PHD

The influence of mineral nutrition, stage of harvest and flower position on seed yield and quality of Phaseolus vulgaris L.

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THE INFLUENCE OF MINERAL NUTRITION, STAGE OF HARVEST AND FLOWER POSITION ON SEED YIELD AND QUALITY OF *PHASEOLUS VULGARIS* L.

Submitted by

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DEDICATION

I would like to dedicate this thesis to my parents, Fotios and Aikaterini, who not only favoured this academic work but also generously provided me with the necessary moral strength and encouragement.

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GENERAL SUMMARY

In this work the effects of mother plant nutrition and flower position on the plant in relation to different harvest stages on French beans *(Phaseolus vulgaris* L. cv. Cascade*)*; seed yield, quality and progeny performance have been studied.

In three pot experiments under glass and one in the field, different levels of nitrogen, phosphorus, potassium and molybdenum were applied to the mother plant and it was found that higher seed yields were obtained with the higher nutrient levels tested, but these high seed yields were not necessarily accompanied by high quality. Seed yield and quality increased with the increase of nitrogen and potassium. The phosphorus effect however, was different, in that the seed yield increased in relation to the levels but the seed quality decreased. Molybdenum was found to be necessary in moderate amounts, especially for the seed quality.

The interactions between nitrogen and phosphorus levels (NP) and between nitrogen, phosphorus and potassium (NPK) were found to be very important for bean seed quality, because their significant effect was similar and constantly present in most of the seed vigour components examined. It seems that the combinations of high nitrogen levels with moderate amounts of phosphorus applied to the mother plant resulted in seed of good quality.

In one pot experiment under glass the progeny performance was examined, using seed from the 1st mother plant nutrition experiment

and it was found that the mother plant nutrition affected the progeny in it's early stages. This effect disappeared later and no difference in progeny seed yield was found.

In two pot experiments under glass the bean pods were harvested at different stages and the pods from the main axis were separated from the pods on the secondary branches grown mainly from the axils of the primary leaves. It was found that the quality of seed from the secondary branches was lower than the quality of seed from the main axis. However, this difference in seed quality became less with the later harvests.

The following tests were used to assess seed quality: the official germination test, seedling evaluation test, cold test, and electrical conductivity test. In addition, the seed size was determined and the seeds were analysed for total nitrogen, phosphorus and potassium content.

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A. GENERAL INTRODUCTION

1. THE SEED AND IT'S USES

Deep within the seed is hidden a mysterious source of life, the life of a plant, of more seeds, and of more plants and more seeds.

From very ancient times we have known what seed is and it's role in nature. To Theophrastus (Agnes Arber, 1950) the word seed meant — as it generally does today to practical men — any one-seeded unit, rather than merely a seed, in the strict sense in which this word is used by the modern botanist. Whatever the defects of Theophratus's knowledge of the seed — defects due to failures in detailed observation — his broad general conception, as expressed in 'De causis plantarum' could scarcely be improved. He tells us that "all plant seed has in itself a certain amount of nourishment which is produced with it at the beginning, just as is the case with eggs".

Also Cesalpino (Agnes Arber, 1950) in his work 'De plantis' recorded a number of interesting details about flowers, fruits and seeds. To his thinking, in seed production, the life-history came to its full beauty and perfection, and vivified his interest in the actual seed itself. He also notices that the grain of wheat contains an 'eye' (embryo) which is the essential part of the seed, and if it be destroyed, germinations fails.

Today we know very well from Botany that seed is a derivative of an ovule containing the young sporophyte (embryo). The ovule lies deep within the ovary of the mother flower, and contains an embryo sac and its tiny egg. After fertilization has taken place from a pollen grain, the fertilized egg begins to develop to a young plant or embryo. A group of actively dividing cells is carried down into the middle of the sac by the development of a long tier of cells, the suspensor, and from this terminal group, at first roughly spherical in form, the characteristic embryo of the mature seed begins to differentiate. Meanwhile, the ovule undergoes a series of changes as it develops into the seed. The whole structure grows in size, and the integuments increase in thickness, become hard and woody and close over the micropyle, which appears as a minute opening in the seed coat or may even be obliterated. The scar, or hilum, is the point at which the seed broke away from the stalk, or funiculus, whereby it was attached to the placenta.

The ripe seed is thus a structure in which the partially developed young plant, well protected and provided with an abundant supply of food for future growth, is able to pass through a more or less extended period of dormancy.

So seeds, above all, are a way of survival of their species. They are a way by which embryonic life can be almost suspended and then revived into new development, even years after the parents are dead. They are an end and a beginning; they are the bearers of the essentials of inheritance; they symbolise multiplication and dispersal, continuation and innovation, survival, renewal and birth.

But seeds are not only the propagating material for plants, they are food for man and animals and other living organisms, they are raw material for the fashioning of a myriad of products.

In fact, the cultivation of cereals probably marked the beginning of agriculture and of civilisation. All major civilisations, in the history of man have been founded on cereals, because of their high food value and their ease in storage. The Mesopotamians planted wheat along the banks of the Tigris and Euphrates. The Chinese grew rice in the valleys of the Hwang Ho and Yangtzee, and the Mayas cultivated corn on the dry, flat plains of the Yucatan.

Today man's most important staple foods are derived directly from seeds as they have been since neolithic times. The Graminae, collectively known as cereals, give more food seeds than any other plant family and provide man with his greatest source of carbohydrates as well as some protein and other essential substances. The second most important food family, the Leguminosae, provide seeds which are rich in proteins or carbohydrates, essential to a human diet.

At the present time not only are seeds the most important sources of food, but they are used as spices and condiments, as drugs and medicines and in the making of some of our popular beverages such as, coffee, chocolate and beer. Edible oils are extracted from seeds such as corn, soybean, peanut, coconut, sunflower. But besides these uses, seeds have many commercial uses, such as in the making of paints, varnishes, clothing, soaps, linoleum, jewellery, buttons and many other products.

Finally man has gained much of his knowledge about growth regulators, respiration, cell division, morphogenesis, photosynthesis, and other metabolic processes, by studying the seed or the germinating seedling. But although modern plant scientists have learned much about seeds since the beginning of the last century, much of the mystery of seeds still remains.

The knowledge of the science and technology of seeds is fundamental to a well developed agriculture. As we obtain new germplasm and improved cultivars by breeding and selection, we need well-organised programs for increasing and maintaining seed. If the 'Green Revolution' is to become a reality in the developing countries of the world, the science and technology of seeds should play a key role in it.

2. THE SEED QUALITY

In order to produce an efficient crop, the seed, as the biological basis, must have a series of valuable characteristics. All these characteristics constitute the seed quality, which is recognised as one of the major factors that determine success or failure of a crop. The main characteristics which determine the seed quality are:

1. genetical quality (purity of species, purity of cultivar);
2. physiological quality (viability, vigour);
3. health condition;
4. purity (presence or absence of weed seeds and other undesirable by-products);
5. morphological quality;
6. moisture content.

(Ware and McCollum, 1975; Kahre, 1974; Harrington, 1971).

The seed which the farmer buys from the seed company or from the seed-store, must truly represent a good cultivar and a strain suitable for the conditions and markets contemplated, and must also represent the name of the cultivar which is written outside the container, package or sack. The present rapid development of plant breeding has resulted in many new cultivars. The cultivar characters must be maintained from generation to generation, because the seed in many ways represents hard work and therefore hard cash. Hybrids have led growers to request even greater genetic purity in all cultivars planted.

Seed should not carry disease to infect the new crop. To ensure that it does not, the seed should be grown without contamination. This may be achieved by its production in disease-free areas and by the use of strict control methods.

To be clean, seed must be free of foreign matter, such as other kinds of seeds, dirt, or plant fragments.

Morphologically, the seed must be entire, undamaged and well developed. It must have all these morphological characteristics which identify its species and/or its cultivar. Sometimes a seed lot can be graded in order to give uniform performance in the field, and uniform plants.

The seed must be dried sufficiently and kept in moisture-proof packages in order to reach the farmers in good condition.

Lastly, physiological quality is a very important factor which must be considered very carefully, by anyone who is dealing with seeds. Physiological quality includes the seed's viability and vigour. These two components constitute the so-called physiological quality of seed (Pollock, 1971). Viability is not a problem of serious concern to the seed industry today. Indeed, because of the emphasis on seed quality and legislation, the industry produces viable seeds.

If a seed germinates under 'optimal' conditions, we can say that it is living, and if it fails to emerge it is dead. But in the field the germination conditions are not usually optimal. Many seeds which are living when germinated under optimal conditions fail to emerge when germinated under non-optimal conditions. Here we have to bear in mind that the boundary between living and dead seed is not always distinct. The difference between the two abilities of a seed to germinate under optimal and non-optimal conditions is what we call 'seed vigour'. This is the second component of physiological quality, and the one which is of great concern to the seed industries, farmers and seed-scientists today. This great concern with seed vigour has been shown recently and a lot of research work is being done on this aspect of seed quality.

3. SEED AND SEEDLING VIGOUR

The term 'seed vigour' is being used with increasing frequency by agronomists, seed analysts and associated specialists investigating the relationship between seed germination and field establishment of crops. It is very important to have a very good understanding of the concept of vigour in these days when direct precision sowing is replacing traditional cultivation methods and specific plant populations are required to achieve maximum yields.

Very interesting review papers have been written on seed vigour and they sum up the state of knowledge on it (Heydecker, 1969; Pollock and Roos, 1972; Abdul-Baki and Anderson, 1972; Heydecker, 1972; Perry, 1972; Copeland, 1976; Bradnock, 1975; Perry, 1976). Vigour test committees have been formed by the I.S.T.A. and A.O.S.A. to define vigour and to standardise methods for its determination (Perry, 1972).

From the above mentioned review papers it is becoming clear that a study of vigour must include:

1. The definition of vigour;
2. Effects of vigour;
3. Factors affecting vigour;
4. Tests for vigour.

Definition of Seed Vigour

The agreement on terms is one of the difficulties in the study of a problem. In the study of seed vigour a lot of researchers defined what they meant by vigour and others avoided the use of the term. These definitions varied and all the attempts to define seed vigour are mentioned in the review papers.

Recently the vigour test committee of the I.S.T.A. agreed a broad definition of seed vigour. This definition is: "Seed vigour is the sum total of those properties of the seed which determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence. Seeds which perform well are termed 'high vigour' seeds', while those which perform poorly are called 'low vigour seeds' " (Perry, 1978). It was agreed that vigour is a concept derived from differences in performance between seed lots and that because it is a concept it cannot be quantified. However, specified components of seed vigour can be measured and expressed numerically.

Effects of Seed Vigour

Pollock and Roos (1972), pointed out that the effects of seed vigour are of concern to growers. They mentioned in their review that vigour can express itself in plant growth and crop yield, in seed germination (speed of germination, growth rate), in uniformity of performance and in the presence of morphological abnormalities.

Heydecker (1972) listed four stages at which seed vigour may show its effects:

1. Non-active stage (survival in storage);
2. Performance in the field (survival in the field);
3. Establishment of mature plants;
4. Production of full crop.

The vigour test committee based its definition on the effects of vigour in performance between seed lots. Between these effects are included:

1. Biochemical processes and reactions during germination, such as enzyme reactions and respiratory activity;
2. Rate and uniformity of seed germination and seedling growth;
3. Rate and uniformity of seedling emergence and growth in the field;
4. Emergence ability of seedlings under unfavourable environmental conditions.

These effects of vigour level may influence mature plant growth, crop uniformity and yield (Perry, 1978).

The main effect of vigour is upon the ability of the seed to produce a seedling and establish a plant under the relatively unfavourable field conditions (Perry, 1972). There has been a lot of research work to support this. Since 1924 Eastham, recognised the need for a relationship between germination tests and emergence in wrinkle-seeded garden peas. From that time many reports from different parts of the world have given evidence that germination tests with peas were not always related to field emergence (Baylis *et al*, 1943; Clark and Little, 1955; Matthews and Bradnock, 1967; Perry, 1967).

Schoorel (1957), working with Phaseolus beans found that the correlation between germination and emergence declined as soil conditions deteriorated. Different seed lots of Phaseolus beans responded differently to high soil moisture content (Heydecker, 1967) and low temperature (Pollok, Roos and Manalo, 1969).

Several researchers have examined carrot establishment. Frank in 1930, reported a poor correlation between germination and emergence in carrots and his results have been confirmed by recent studies (Hegarty, 1971). Richardson in 1970, working with *Brassica* spp. made a trial in which the seeds were sown at the normal planting time and found a coefficient of only 0.52 between germination and emergence for cabbage and savoy seed and for rape, kale and broccoli group found a better one of 0.82.

Onion seed was observed to differ in vigour by Cole in 1926, and it was found that seed which was going to fail in the field, produced a high proportion of abnormal seedlings. Clark in 1944, again with onions found that an average of 65.7% seedlings emerged per 100 viable seeds sown in good soil conditions. Examining his data we can see that a range of emergence from 35 to 75% was achieved from seed lots with germination of around 85%. Clark and Kline (1967) examined spinach seed lots in a similar way and found that emergence was greater in lots with a high germinating capacity than in lots of poorer germination.

But the influence of seed vigour may persist through the life of the plant and may affect the plant growth and the final yield. Since 1923

Brenchley, found that differences in seed size of peas and barley were expressed in yield. Fleming (1966) comparing hybrid corn seed lots produced by different growers, found differences in yield between lots with the same laboratory germination. Similar results have been recorded by Perry (1969b), with peas and Clark and Kline (1965), with tomatoes. In studies with carrots on the effects of seed harvest date and seed size on plant establishment and yield it was found that early-harvested seed which was immature and therefore of low vigour emerged less well and gave a lower root yield up to six weeks after sowing than seed of comparable size harvested when mature. But after the 6th week the differences in root yield disappeared, presumably due to inter-plant competition (Austin and Longden, 1967b).

Lange (1965) working with radishes reported that plants from poor quality seed matured later and produced smaller roots than those from good quality seed and equal size. Perry (1969a), recorded yield reductions of 16.5% and 18% from low-vigour pea seed lots compared with high-vigour lots of the same cultivar grown at the same plant populations in the field. Snap bean seeds, stored under poor conditions, and consequently of low vigour produced plants with less growth and final yield than seeds stored under good conditions (Toole *et al*, 1957), and low yields were associated with low vigour in field beans (Vieira, 1966). Chen *et al* (1971), stored seed of squash, turnip and radish at high moisture and temperature to achieve low vigour. These seeds produced plants which yielded less than those from seeds stored under dry conditions and normal temperatures.

Abdalla and Roberts (1969) exposed barley, broad beans and pea seeds to high temperature and moisture, to reduce their vigour to low levels. A study of the growth of plants from these seeds showed that growth increases were dependent on the quantity of actively photosynthesizing plant tissue present, and that the early growth of roots and shoots was decreased, but during the later stage of growth the differences in plant growth were lost and there was no significant effect on final yield. But if the seed deterioration during storage caused a loss of viability below 50%, they produced small, slow-growing seedlings and the plants never compensated and yielded as much as ones from non-deteriorated seed.

Factors Affecting Seed Vigour

Heydecker in his review papers (Heydecker, 1969; Heydecker, 1972) stated that lack or loss of seed vigour can be due to a number of causes, and he classified them as follows:

1. Genetic;
2. Physiological;
3. Morphological;
4. Cytological;
5. Mechanical;
6. Microbial.

Perry in a recent review (Perry, 1976) recognises that in practice the agronomist and seed analyst do not know the history of the seed lot under examination, therefore the causes of the differences in vigour are unknown. However, there are several causes which have been determined and he classifies them into two groups:

1. Intrinsic variations due to genotype;
2. Variations because of the external environment which interact upon the genotype.

More recently the vigour test committee (Perry, 1978), mentioned the principle known causes which change the level of seed vigour.
These are:

1. Genetic constitution;
2. Environment and nutrition of the mother plant;
3. Stage of maturity at harvest;
4. Seed size, weight or specific gravity;
5. Mechanical integrity;
6. Deterioration and ageing.
7. Pathogens.

Genetic Constitution

From the points mentioned above it is becoming clear that the maximum possible seed vigour is determined by the genotype, thus, differences in vigour between different species and different cultivars. The influence of genetic control on seed and seedling vigour may be clearly illustrated by the higher seedling vigour of hybrids and polyploid plants over inbred and diploid plants of the same species. For example, seeds of barley hybrids have been germinated faster, grow faster and gave clear evidence of higher respiration rate than their parents (McDaniel, 1969). Similar observations have been made for corn (McDaniel and Sarkissian, 1968; Whaley, 1950). Donaldson and Blackman (1974) working with corn showed that during germination, the embryo of the hybrid gained in dry weight faster than that of the parents, although the initial size was similar. The greater growth rate of the hybrid embryo was associated with an increased rate of cell division. According to Te May Ching (1973), higher vigour of hybrid seed has been associated with super-efficient mitochondria and extra-active enzyme systems for assimilation.

Deakin (1974), comparing F4 lines of *Phaseolus vulgaris* which were nearly homozygous for colour of testa found that seeds with coloured testas produced more seedlings in cool and warm soil. Similarly Carter (1973), showed that coloured seeds of groundnut were resistant to fungal invasion in the soil. Another genetic cause of low vigour is illustrated by poorer seedling vigour of lima beans with bleached cotyledons compared to higher vigour of non-bleached beans (Pollock and Toole, 1964; Wester, 1970). Kooistra (1971), in a study of germination of beans found that *Phaseolus trilobus* Ait. and *Phaseolus coccineus* L. germinated better at low temperatures, and that there were differences between cultivars of *Phaseolus vulgaris* L. especially at soil temperatures below 15^{o}C. Furthermore, he showed that this ability to germinate at low temperatures can be inherited.

Seed Size

Seeds are usually separated by diameter, weight or density. According to Heydecker (1972) the seed weight and the seed density are more important than the volume of seeds for distinctions in vigour. And indeed, the 'thousand seed weight' of seed lots is often given as part of sales information. Heydecker (1972) again suggested that there are two possible reasons for this: "sowing rates are more logically adjusted by number than by weight; and larger seeds are often considered better seeds".

Since 1876, when Nobbe in his book 'Handbuch der Soumenkunde' noted that large seeds of cereals produced larger seedlings than small seeds from the same ear of the mother plant. The interest in the effect of seed size continues to the present time. A lot of papers have been published with research on this subject. Hewston (1964) found that in many vegetable species larger seeds produce larger seedlings, but in the field these differences usually disappear after a few weeks of growth. Investigating the importance of seed weight on lettuce growth, Scaife and Jones (1970) found that there is a linear relationship between the fresh weight of the plant tops at harvest and the weight of the seed sown, under uniform conditions and in the absence of inter-plant competition. Sharples and Kuehl (1974) in their work with lettuce, separated seeds of four cultivars into eight groups according to their length, width, thickness and weight. Their results show that germination percent and rate were not related to size, but radicle growth after seven days was associated with weight and thickness of the seed.

Austin and Longden (1967b) working with carrots found that within any sample of mature seeds, those of large diameter had a greater advantage over those of a smaller diameter, regarding germination percentage and seedling emergence. The roots grown from large seeds remained heavier for the first four months of growth. But in Austin and Longden's work the time of harvest affected the performance of all sizes but particularly of the small carrot seeds, e.g. the increase in germination percent was bigger in the small seeds from the late harvests than in the large seeds. In another work with carrot and onion seeds by Bedford and Mackay (1973) an interaction was clearly demonstrated between carrot seed weight and depth of sowing. They reported a close positive correlation between field emergence and seed size when sown 25 mm deep in dry soil but not at 19 and 13 mm. They did not find a relationship between seed weight and emergence in onion seed lots.

Mechanical Damage

It is well known by seed technologists and seed analysts that one of the most serious causes of low vigour is mechanical damage. Heydecker (1969) and Pollock and Roos (1972), in their review papers provide evidence which shows that mechanical damage can be caused during harvesting, processing or sowing and can be expressed as loss of storage and meristematic tissue, invasion by fungi and shortening of storage life.

Deterioration and Ageing

It is well known that when seeds have reached their maturation they attain their maximum potential viability and vigour soon after (Pollock and Roos, 1972; Perry, 1976). Following these stages and while seeds age, they undergo gradual changes, which have as a result a reduction in their viability and vigour. From the same review papers it can be concluded that, the rate of decline is a function of moisture content and temperature, and that the process of deterioration may start while the seed is still on the plant, especially if adverse weather conditions delay the harvest, and continue during storage. Unfavourable storage conditions such as high humidity and temperature have frequently been used to induce and study low vigour in seeds.

In the present research work with *Phaseolus vulgaris* L. the effects of the remaining factors, e.g. mother plant nutrition and stage of maturity at harvest together with fruit position on the mother plant are examined. The relevant literature is reviewed in the following chapter.

Tests for Seed Vigour

Seed vigour testing has become an increasingly important component of seed analysis, since increased emphasis is put on the seed vigour. The germination test gives information about the seed performance under optimal or standard conditions, thus additional vigour tests are required to supplement the germination results and to provide growers with better prediction of the performance of the seed under non-optimal conditions.

Many tests have been proposed and they have been reviewed by different workers (Heydecker, 1969; Isely, 1957; Moore, 1968; McDonald, 1975). Some of them classify the vigour tests into three groups:

1. Physical tests, which measure seed characteristics (e.g. size, weight and density);

2. Physiological tests, which use some parameters of germination or growth;

3. Biochemical tests, which investigate reactions involved in cellular maintenance.

The vigour test committee (Perry, 1978) gives the definition of the vigour test and its principles. According to this committee "vigour test is a reproducible laboratory method which distinguishes seeds of different levels of vigour". Furthermore a vigour test " ... must have been proved to be correlated with a field performance characteristic such as seedling emergence under environmental stress".

The same committee divides the possible vigour tests into two categories as follows:

1. Direct tests, in which an enviromental stress in the field is reproduced in the laboratory, e.g. Hiltner test, Cold test.

2. Indirect tests, tests in which other characteristics are measured, e.g. respiration rate, conductivity test.

4. THE IMPORTANCE OF PRODUCING HIGH-QUALITY SEED

According to estimates made by the FAO (1969), the population growth rate in the developing countries during the period 1962-85 would require an 80% increase in food supply. To achieve this an annual rate of increase of almost 4% in agricultural production would be necessary, which is substantially higher than the average in developing countries of about 2.5% annually during the last 15 years (Feistritzer, 1975). On the other hand it is well known that the main inputs which affect the agricultural production in a modern agriculture are:

1. Improved seed;
2. Irrigation;
3. Fertilizers;
4. Crop protection;
5. Mechanisation;
6. Careful harvesting;
7. Proper storage.

But further use of inputs, such as fertilizers, crop protection chemicals and machinery for increased agricultural production is difficult because of the rapid increase in their cost.

It has been shown (Feistritzer, 1975) that those technologies which require the least changes in existing techniques have the best chance of being adopted quickly. It is therefore no great problem to introduce biological technologies to farmers, such as the use of seed of improved and adapted cultivars. This high quality seed in interaction with other inputs has the genetic ability to increase crop yields substantially. No amount of fertilizer, weeding or careful husbandry will compensate if the seed sown produces plants which are incapable of exploiting the environment in which they have been planted. The decades since the Second World War have seen remarkable advances in plant breeding. The successful development of new cultivars by the plant breeder however, though of basic importance, marks only the first step in the long process of multiplication, certification, and commercialisation before their widespread adoption on a farm scale can have a major impact on total agricultural production.

In the case of vegetable crop production, apart from the increase on the crop yield, there are further reasons for the need for high quality seed which make seed production more important. Harrington (1971) pointed out that the necessity for high-quality seed in vegetables has arisen from at least three sources. First, the change from hand production has come about only by the development of specialised machines, such as precision planters, electronic thinners and mechanical harvesters. These machines are only economically successful if high-quality seed is used. Second, the type of vegetable farm is changing from small family operations, where book-keeping is minimal, toward corporate farming, where profit is essential and the cost of every operation is carefully scrutinised. College-trained growers and staff are aware of the need for high-quality seed and know what factors are involved in quality. Third, the seed business is one of the most competitive in our society, with the competition based on high quality rather than low price. Since seed costs for most vegetable crops are as low as 1% of the grower's production costs, it is ridiculous to buy cheaper seed if even a small part of the high quality is sacrificed. Even a 1% gain in yield will pay for all the seed cost. Hence, seedsmen are finding ways of producing seed of the high quality that growers want.

Because of these points and since most vegetables and flowers have to be started from seed, which is produced, distributed and sold by professional seedsmen, the seed production is an important and fundamental segment of agriculture. The seedsman supplying the seed greatly influences the grower's profit by the quality of the seed which he supplies. Thus the seed producer, private or public, stands in a position of great responsibility, and to fill his obligation satisfactorily he needs to understand thoroughly many factors which enter into the production and processing of good seed.

There is growing awareness of the importance of high-quality seed production all over the world. FAO pays a lot of attention to the improvement of seed production, especially in developing countries, organising seed industry development programmes and sending specialists to improve the local seed production. George (1978) indicated how some of the problems associated with the high-quality seed production of horticultural crops in developing countries may be identified and tackled. He recommends that before seed legislation, including certification schemes, is introduced in a country, other seed improvement programmes must become effective. Such programmes are an overall assessment of the seed situation in a country, the identification of cultivars for seed production, the practice of commercial and basic seed production, the improvement of agronomy, mechanisation, and seed storage and finally the manpower education and training.

B. REVIEW OF LITERATURE

1. EFFECTS OF MOTHER PLANT NUTRITION ON SEED YIELD, QUALITY AND PROGENY PERFORMANCE

There is common agreement today that mineral nutrition of the mother plant affects seed quality, (Perry, 1972; Austin, 1972; Pollock and Roos, 1972; Copeland, 1976; Perry, 1978). Pollock and Roos (1972) in their review paper draw the following general conclusions:

a. Any reserve nutrient that can control the rate of seedling development, under any set of conditions, is a potential factor in seedling vigour.

b. Any environmental condition that influences accumulation of nutrient reserves in seeds has the potential for influencing vigour in the next generation.

Austin (1972) says that the mineral composition of seeds is influenced by the mineral nutrition from an early stage of their mother plants and that the effects of environmental factors on seed quality and performance have not been studied so extensively. Although there is some evidence to support the influence of the mother plant nutrition on seed quality, in practice there is no information available at present concerning these effects of the environment in which the seed crop is grown (Brocklehurst, 1978).

The first investigated effects of the mother plant mineral nutrition were the effects of the plant's nutrient deficiency on seed performance. Harris (1912) investigated three pure lines of

Phaseolus vulgaris grown in two fields, one described as fertile and the other as infertile. The fields subsequently received similar cultivation and produced seed crops with differences in growth, but Harris did not suggest that these differences were due to lack of any specific nutrients. Seeds from plants produced in both fertile and infertile fields were sown in a 'comparison field'. The seeds from the infertile field gave plants with slightly, but consistently, fewer pods per plant than those from the fertile field.

Subsequent studies have been made by different workers attempting to explain the effects of mineral elements on seed production. Nitrogen, phosphorus and potassium have been the main nutrients examined and in addition some of the micronutrients, each one separately or in combination with others. Nitrogen and phosphorus seem to play the most important role in seed production, but there are two main groups of opinion as to the effects of each. According to one of them, phosphorus is the most vital element for the seeds, since seeds with high phosphorus content perform better in the field. The other group considers that nitrogen is the most important element for seed production, because it is mainly responsible for the increase of seed protein, which is one of the most important reserve foods for the young seedling.

Indeed, phosphorus has always been considered an essential element for the formation of inherent parts of cells, and as seeds consist of cells as units, phosphorus must be necessary for the formation of seed. MacGillivray (1925), reported that researchers working with cereals found that in the mature cereal plant over one half of the phosphorus was in the grain, and that the use of phosphate fertilizers increased grain production and earliness of ripening. With his work on tomatoes, MacGillivray indicated that the percentage of phosphorus found in the seed portion is always greater than in the non-seed portion. The total amount of phosphorus in the non-seed portion was however, greater than in the seed portion and the reason is that the dry and fresh weight are greater in the non-seed part. The presence of phosphorus in greater amounts in the non-seed portion of the fruit, regardless of age or phosphorus regime, demonstrates that phosphorus is just as important in the production of the non-seed portion as the seed portion of the fruit. But MacGillivray did not examine the effects of the different phosphorus nutrient treatments on seed quality.

Anisimov and Popova (1954), also working with tomatoes, found that more phosphorus fertilizer given to the mother plant resulted in seed which produced not only taller and more vigorous seedlings, but earlier fruit ripening and more fruit yield in the progeny.

Iwata and Eguchi (1958) in their experiments with chinese cabbage, examined the effects of phosphorus and potassium supplied at different growth stages on seed yield and quality. They concluded from their results that in the early stages especially, phosphorus is necessary for good seed yield. For seed quality they measured the phosphorus concentration in the seed, percentage of germination and the radicle elongation rate. Their results indicated that the earlier the stage of growth at which phosphorus supply was stopped, the lower was the seed phosphorus concentration. There were no differences in germination percentage among treatments, but the rate of radicle growth has been shown to increase with increased phosphorus application during seed development. The potassium supply only affected the seed yield in the case where it was withheld during the very early stages, but did not affect the seed quality.

The importance of phosphorus on flax and rape seed has been investigated by Szukalski (1961a, 1961b). In pot experiments he applied different levels of phosphorus before and after sowing, including post-emergence. As a result, seeds were obtained with a different percentage of phosphorus. The influence of the phosphorus content in the seeds upon the yields was investigated in pot experiments in pure quartz sand and in soil. Seed with higher phosphorus concentration, sown in soil which was low in phosphorus, germinated faster and uniformly, produced plants which flowered earlier, had a better growth at the beginning of vegetative period and a higher final yield. But in soil high in phosphorus this difference in growth was observed in the beginning, but not in the final yield.

In addition, very interesting work on the importance of phosphorus on seed quality has been done by Austin and Longden (1965). They conducted a series of experiments with watercress, peas and carrots. Their results indicated that parent plant nutrition can affect the concentration of phosphorus in seeds, which in turn may affect plant yields. Austin (1966a) in his experiments with watercress, collected seed from plants grown in sand cultures supplied with nutrient solutions containing 0.2, 1.0 and 4.0 me/l of phosphorus. The seed from P1, P2, P3 treatments contained 0.47, 0.84 and 0.95

percent phosphorus respectively. Other differences in seed composition and seed size were relatively slight. These P1, P2, P3 seeds were grown on a range of phosphorus levels. Plants from P3 seeds grown in deficient conditions were larger than those from P2, when they were 7-9 weeks old , which in turn were larger than those from P1 seed. But these differences were not measurable when the plants were mature at 16-20 weeks. All these differences disappeared when the seeds were grown in cultures adequately supplied with phosphorus. Also the different levels of phosphorus supply in the first generation had no effects on $6\frac{1}{2}$ week old plants in the third generation.

Austin (1966b) has done similar experiments with peas, grown in vermiculite and watered with four different nutrient solutions. With these experiments he examined the influence not only of phosphorus but in addition, nitrogen nutrition on the growth of their progeny. Again seed from phosphorus deficient plants contained much lower phosphorus concentrations than seed from plants not deficient in this element. Differences in the supply of mineral nitrogen had little effect on the chemical composition of the seed. He later observed that low-phosphorus seeds, in cultures deficient in phosphorus, produced plants which gave lower yields in haulm and seed weights, than high-phosphorus seed. In cultures not deficient in phosphorus there were no differences in the seed performance. Similar results have been obtained when low- and high-phosphorus seeds were grown on a fertile soil. The low-phosphorus seeds gave 20 to 25 percent lower yields of both haulms and peas compared with yields obtained from sowing of high-phosphorus seeds. Austin concluded that these differences in seed performance were related to differences in the phosphorus concentration, rather than to any other variation in seed composition or size.

Austin and Longden (1966b) in their work with carrots examined the effects of nutrition with nitrogen, phosphorus, potassium and farmyard manure on seed yield and quality. Their results showed that the seed yield responses were significant and each of the main nutrients and the farmyard manure gave better seed yield than the control plots with no manure or fertilizers. The germination of the seed produced was above 60% and there were no signficant differences in germination caused by the manurial treatments. The chemical composition of the seed produced in 1963 and 1964 was affected by the nitrogen and farmyard manure dressings, but these variations did not affect the progeny performance. The seed produced in 1962 had a lower mean phosphorus concentration than the commercial seed. The seed with the lowest phosphorus concentration was obtained from plots which had received nitrogen but no phosphorus fertilizers. The root yields from such seed were significantly lower than those from the seed containing higher concentrations of phosphorus. Thus these results with carrots, confirmed Austin's previous work with watercress and peas.

Lipsett (1964), working with wheat reported that phosphorus concentration in the seed is important for the seed performance. He collected 20 representative samples of wheat containing an average of only 0.25 percent phosphorus, from phosphorus deficient sites in Australia. In pot experiments the wheat grain phosphorus concentration increased to 0.45% by applications equivalent to 150 Kg P_2O_5/ha. He noticed that cultivars responsed differently in their behaviour in these deficient soils, some giving more grains per ear with a lower phosphorus concentration than others.

More recently Maxon Smith (1976), working with lettuce studied the cultivar effects, pot type, frequency of liquid feeding and feed composition on seed yield, seed weight, seed germination and progeny performance. He applied two different liquid feeds, one with phosphorus fertilizer and one without. He obtained conflicting results for seed yield and for seed weight, but there was outstanding uniformity of seed germination and progeny plant performance.

Maxon Smith's work is in agreement with Harrington's (1960) work. Harrington produced seed of carrot, lettuce and peppers grown in sand cultures receiving either a complete nutrient solution or one deficient in N, P, K or Ca. According to his results, seed yields were always depressed by low N, P, K or Ca treatments, but the germination of normal seeds from the low N and P treatments was not different from that of seeds from complete solution treatment. The K deficiency resulted in a lower germination in some experiments and Ca deficiency resulted in lower germination in the carrot and pepper experiments. Also in storage, seeds from the low K and Ca treatements declined in germination faster than seeds from the complete-solution treatments.

Very early work concerning the effects of all the main nutrients, N, P, K and manure, in different combinations has been done by Claypool (1932). He worked with lettuce and studied the effects of mineral nutrition and farmyard manure not only on seed production and seed size (as 1000 grain weight) but on weight of heads as well.

The results from his work indicated that in that particular soil nitrogen was the chief factor, not only for market crop but for seed yield and size. Phosphorus was the second limiting factor for both the fresh product and seed yield and size, while additions of potassium to the soil were of no apparent benefit in seed development. Claypool noticed that there was a positive correlation between the size of the heads and the number of flowers produced on the seed stalk. This indicated that the nitrogen supply probably increased the number of flowers by producing a large leaf area, which in turn stored up larger quantities of nutrients helping flower bud formation and development.

Fox and Albrecht (1957) with their comprehensive study of fertility and seedling vigour in wheat showed definite influence of fertility supplied to the mother plant and subsequent seedling vigour. In this study there is evidence that climatic factors modified the effect of nitrogen fertilization, so that during a favourable year seedling emergence was improved when nitrogen content of the seed increased, but this did not happen during an unfavourable year. Moderate amounts of phosphorus improved seedling emergence but large quantities depressed it. From this work there is evidence that fertilization for high yields may not give seeds which are highest in quality. Indeed, Fox and Albrecht (1957) found that seed which came from plants fertilized with large quantities of main nutrients, and trace elements in addition, were often among the lowest in giving vigorous seedlings, so they concluded that a balanced mother plant nutrition is of more importance. In the same work, the effects of the mineral nutrition on seed chemical composition, phosphatase activity and respiration have been mentioned. Nitrogenous fertilizer increased the nitrogen content and decreased the phosphorus content of both seed and embryo, since higher rates decreased the size of both seed and embryo. Phosphatase activity per unit of protein-nitrogen was increased by nitrogenous fertilizer, while less inorganic phosphorus was liberated from the seed of higher nitrogen content. Two measures of respiration failed to indicate any important constituent changes in this process by either the nitrogen or phosphorus content of the seed.

Hawthorn and Pollard (1958) found from a lettuce field experiment that seed yields increased as the applications of nitrogen were increased from 0 to 40 to 80 pounds per acre but did not respond any further to an application of 160 pounds. They noticed that plant height differences due to nitrogen were small but consistent. The tallest plants were associated with the greatest nitrogen applications but there was no effect on either time of seed maturity or viability due to nitrogen. Similarly, phosphorus had no measurable effect on seed yields, time of maturity, plant height and seed quality.

In similar work Hawthorn and Pollard (1966) found that the addition of nitrogen fertilizer decreased pea seed yield and germinability, while applications of phosphorus fertilizers ranging from 0 to 150 pounds of P_2O_5 per acre produced no valid differences in pea seed yield or viability.

Seth and Dhaudar (1970) and Seth and Choudhury (1970) studied the effects of nitrogenous and phosphorus fertilizers along with spacing on fruit yield and seed yield and quality in tomatoes and egg plants. With the eggplant they found a signficant effect of the highest rate (70 Kg/ha) of nitrogen on fruit and seed yield, as well as on quality. There was no significant response to phosphorus fertilizer. With tomatoes, they found that the highest rate (90 Kg/ha) of nitrogen gave the highest fruit and seed yield. There was no significant difference between the P_2O_5 levels. However, they observed an improvement in fruit and seed yield as well as in quality due to interaction between nitrogen and phosphorus, e.g. the second level of nitrogen performed better with phosphorus levels than the first level.

A factorial experiment was conducted by Singh and Cheena (1972) on radish seed production. The factors examined were irrigation, at three levels, nitrogen at two levels, and phosphorus at two levels. The results indicated that different levels of nitrogen and phosphorus did not have a signficant effect individually. However, a higher level of nitrogen and more frequent irrigation delayed seed maturity, while a higher level of phosphorus and increased interval of irrigation brought early maturity of seed.

According to Painter (1977) application of nitrogen, phosphorus, potassium, zinc, manganese, iron, copper and boron fertilizers did not improve onion seed yields. Combinations of zinc and iron, in fact, may have reduced seed yield.

Varis (1976) working with glasshouse tomatoes examined the effects of nitrogen and phosphorus fertilizers on fruit and seed yield and seed quality as well. Fruit and seed yield were greater with the higher phosphorus level. Thousand-grain weight was higher with a moderate dose of nitrogen. The effect of nitrogen and phosphorus interaction was marked on germination and seedling emergence rates which were fastest with higher doses of both nitrogen and phosphorus.

The necessity of balanced mother plant mineral nutrition have been stated by Al-Bahash (1978) in his work with lettuce. He grew lettuce in experiments until seed production. The mother plants were supplied with liquid feeds consisting of different levels of the main nutrients nitrogen, phosphorus and potassium. He did not find marked effects on the germination percentage or progeny performance, but there were differences in seed yield and 1000 grain weight.

In contrast to all these studies mentioned above, another group of workers demonstrated that the role of nitrogenous fertilizers is very important to seed production. They related the nitrogen consumption by the mother plant to the protein increase in the seed and with the seed performance.

Eguchi (1960) examined the effects of nitrogenous fertilizer, applied at different stages of growth on seed production in cabbage and chinese cabbage. A part of the nitrogenous fertilizer was applied as a side-dressing at the flower bud differentiation stage, the transition stage of floral development, the time of bolting, and the flowering period. From the results obtained he made the following conclusions:

1. Nitrogenous fertilizer applied at the bolting stage increased the numbers of secondary branches, flowers and fruits.
2. Application of nitrogenous fertilizer at flowering resulted in a high percentage of fruit setting.
3. The seed yield was higher in plots where nitrogenous fertilizer was applied at bolting time.

4. A high positive correlation was obtained between the number of secondary branches and yield of seeds.

To estimate the seed quality he measured the 1000 grain weight and germination percentage. He did not find any significant differences in these two components of seed vigour.

The work concerning the nitrogen effects on seed production and seed performance and its relationship with the seed protein has been mainly done with cereals. Terman *et al* (1969) working with wheat, and looking at the seed quality for food purposes, found that there is a highly significant inverse yield-protein relationship in wheat grain at each level of applied nitrogen under irrigated conditions. They also found that in dry land experiments, when there was a significant grain yield response to applied nitrogen,seed protein content was also increased. The authors suggest that yield-quality relationships may vary according to the type of agriculture.

The importance of seed protein content has been pointed out by Schweizer and Ries (1969). Summarising their work with cereals, they concluded that there is a positive correlation of seed protein and amino acid content with growth and vigour of emerging seedlings. They found that the increase in seedling growth was not due to seed weight, since the seeds used were uniform. They suggested that some other substance or substances contained within the seed may have been altered by treatments used to increase protein content. According to them the maintenance of high protein seed for a given genotype may be very important for the progressive development of major agronomic crops.

Ries *et al* (1970), in their work with wheat, applied simazine and terbacil at sub-herbicidal rates, and different nitrogen levels in experiments with wheat at different locations in the USA. Their aim was to determine the effect of herbicide and nitrogen treatments on the growth, yield and protein content of the second generation. Nitrogen increased both the yield and protein content in three out of four trials and sub-herbicidal applications increased the protein content in all trials and the yield in two. In order to study the relationship between seed protein content and the progeny performance, lots of wheat seed from the nitrogen and herbicide applications were used. Increases in seed protein content due to both herbicide and nitrogen applications were reflected in higher yields in the next generation in all three Michigan field experiments. The yield of the second generation was most closely associated with the seed protein content and not seed weight. Finally, they suggested that it may be practical to use growth regulating chemicals and/or nitrogen to produce high protein seed for subsequent crop production.

Another way to study the relationship between seed protein content and progeny performance has been used by Lowe *et al* (1972). They collected samples from 17 phenotypes of a Mexican semi-dwarf wheat, from different localities. These were analysed for protein and amino-acid composition. These parameters were related to seedling vigour and yield to determine if amino-acid composition was a better estimate of the progeny performance than seed protein. The same procedure has been followed with samples from different fertilizer treatments and different growing seasons. Seedlings from these different phenotypes were grown in the laboratory for 3 weeks.

Shoot dry matter after the 3 weeks was positively related to the protein content of the seed. There was also a high positive relationship between total amino acids, expressed as μ moles amino acid/g seed meal, and shoot dry matter, and between total amino-N in μ moles N/g seed meal and shoot dry matter. In a field trial, 12 wheat phenotypes from another field trial were grown for second-generation grain yields. Again a positive relationship was found between both seed protein content and mole percent glutamic acid and grain yield. With these results the authors suggested that the amino-acid analysis indicated the possible source of protein contributing to increased seedling vigour but they did not prove that amino acids give a better estimate of seedling vigour, or yield than nitrogen analysis. They also suggested that seed produced under low nitrogen conditions undergoes protein depletion which has a 'running-out' effect.

Ries and Everson (1973) with another experiment on wheat following the results from previous experiments, tried to determine the relative contribution of genotype and environment in determining seed protein and seed size and then to relate these effects to seedling vigour. To test these suggestions they collected spring and winter wheat seed from five cultivar trials grown at several different locations. In one of these trials they also applied urea as foliar feeding after anthesis. The results from these experiments indicate that both environment and genotype affected the protein content of the seed. Regardless of genotype or environment, seedling vigour was also related to seed size, but when seed size was eliminated by using uniform seed, the seed protein content and vigour relationships were significant. In the case of the nitrogen foliar application to eight soft winter wheat cultivars, seed size and seed protein increased over the untreated controls, and were associated with greater seedling vigour as determined by recording shoot dry weight after sowing in vermiculite. They suggested that it may be beneficial for seed producers to increase the protein content of seed by foliar applications of nitrogen.

Similar work with wheat has been done by Lopez and Grabe (1973). They obtained seed of different protein contents by autumn and spring applications of various rates of nitrogen to soft white winter wheat cultivar. The increase in protein content from high nitrogen rates was accompanied by a decrease in seed size. They observed that the increase in protein content occured primarily in the endosperm and neither protein content of the embryo nor embryo size was affected by the rate of nitrogen application. The results from the seed quality testing pointed out that rates of water absorption and oxygen consumption of germinating seed increased because of the higher protein content. Seeds with higher protein content had a faster germination and developed into larger seedlings with a higher dry matter content when grown in nitrogen deficient soil. Seed with high protein content performed better under stress conditions when plant growth depended on the nutrients available from the seed. They also found in contrast to the findings of Ries *et al* that after the seedling was formed the effect of seed protein content on plant growth was influenced by the amount of soil nitrogen available to the plant.

Similarly Holzman (1974), also working with wheat confirmed Lopez and Grabe's results and demonstrated that in the laboratory, seed with high protein content produced taller and heavier seedlings than those of low protein content but in a pot experiment produced no yield advantage.

In the work with seed production in cereals and the importance of seed protein content for the progeny performance none of the authors analysed the seed components completely, especially to determine the phosphorus concentration in the seed. However, Austin and Longden (1966a, 1967a) in nutritional trials with carrots, red beet and radish, analysed the seed produced and found a negative correlation between the concentrations of nitrogen and phosphorus. Eight main plots (a 2^3 combination, of zero and high application rates of N,P and K fertilizers) were split, half at each plot receiving three sprays of urea at flowering. Chemical analysis of radish seed showed that seed from plots to which no nitrogenous fertilizer had been applied, had a nitrogen content of 4.24%. This was increased to 5.31% by the nitrogen fertilizer, to 4.9% by the urea spray alone, and to 5.69% by both together. But increases in nitrogen content of the seed, accompanied by a reduction in their phosphorus content, which varied in the experiment with radishes from 0.98% to 0.67%. However, Austin and Longden failed to find differences in the progeny performance due to differences in N and P concentrations.

Scott (1969), applied nitrogenous fertilizer in sugar-beet, and found that the seed crop showed depressed germination, only in years when the crop ripened late. The main effect of nitrogen was a delay in seed ripening, thus the seed from the plots fertilized with nitrogen was less mature at harvest than that from the plots which received less, or no nitrogen. Thus the reduction in germination was a nitrogen induced maturity effect.

Contrasting results have been found by Hartwig and Hinson (1972) for the relationship between high seed protein levels and yields of soybeans. Selections of soybeans which were high in oil percentage were low in protein percentage and vice versa. Progeny yield was positively correlated with high oil levels and negatively with high protein levels. However, backcrossing experiments suggested that it was not high protein level responsible for the reduced yield. It was found possible to cross high protein and high yielding selections and select a higher yielding high protein line.

Soffer and Smith (1974b) reported nutritional effects on yield, vigour and composition of lettuce seed studied simultaneously by two approaches: (1) the level of overall nutrient in the soil (fertility) and (2) the level of nitrogen only, which was varied in the nutrient solution. Five levels of soil fertility were obtained by incorporating nutrient solution into the irrigation system at varying intervals. Seed yield was highly correlated to soil fertility and increased nutrient level added to the soil increased seed yield but did not give an increase, similarly, in seedling performance. From the experiment with the nitrogen treatments a positive linear correlation was found between nitrogen levels and seed yield, weight per seed, and seedling vigour. The amounts of amino acids and lipids were not positively correlated with nutrient supply, nitrogen level, or seedling vigour. The authors confirmed that the lettuce seed weight was a useful parameter in predicting seed vigour only within a seed lot obtained from plants grown under the same environmental and nutritional conditions.

Trevino and Murray (1975) studied the effects of nitrogen on pea seed production. The experiments were conducted in a glasshouse and nitrogen was applied as ammonium nitrate at seven equally spaced intervals at nitrogen rates of 0, 50 and 100 ppm. Seven pea cultivars were used. The intermediate rate of nitrogen increased the total seed protein of five cultivars and the increase was due to an increase in protein/seed and higher seed yield. The highest rate of nitrogen depressed the seed yield. The results from this experiment demonstrate that different pea genotypes respond positively to nitrogen fertilization. Moderate increases in seed yield accompanied by considerable increases in percent protein content in the seed. The authors also made the suggestion that efficiency of nitrogen translocation to seeds could be a useful tool in genotype selection for improved seed protein content.

Another approach in the effects of mother plant nutrition on seed production and progeny performance is the work of Durrant (1958, 1962). He carried out extensive experiments with one cultivar of flax, studying the transmission of responses to fertilizer treatements applied in one generation, to subsequent generations. He reported large heritable changes occuring. The fertilizer treatments were eight combinations of N,P and K in two levels each, applied and not applied. The differences in the weights of the progeny were considerable and they were closely correlated with the weights produced by applying the fertilizers directly to the plants. These differences continued to appear for several generations. From the eight phenotypes produced, Durrant defined three types, a larger form, a smaller form and a plastic one. The plastic type was changed into the other two types depending on the fertilizer applied. The large and small types were continuously produced by the NPK and NK treatments respectively. Both the large and small forms were stable and had remained unchanged for generations irrespective of the fertilizer subsequently applied. Durrant termed these three types as 'genotrophs' and he demonstrated that when the small and large genotrophs were reciprocally grafted and crossed they behaved like two distinct genetic types and suggested that the nucleus is probably involved in the genotrophic change. Durrant concluded that the induction of heritable change is dependent upon environmental conditions and the plastic properties of the plant. The balance of nitrogen and phosphorus in the nutrients applied plays at least some, if not a major part, in the induction of heritable change.

However, after Durrant's work with flax there has been no further similar work with other plants to confirm or dispute his findings. Only Austin and Longden (1965) reported that they did not find evidence in their work on heritable change of the kind reported by Durrant, although they observed that plants grown from seed produced by phosphorus-deficient plants were more variable in size than those from non-deficient plants.

The results mentioned above, sometimes contradictory, show that more work with more plants should be done, in order to be able to draw conclusions and furthermore to make decisions for practical solutions and recommendations to seed producers and plant breeders. However, it appears that nitrogen and phosphorous availability can influence seed development and seedling vigour, but their effects vary among the different species and are highly dependent on the stage of growth and environmental conditions. The inorganic nutrients stored in the seed seem to provide valuable reserves and to create the so-called 'initial capital' (Heydecker, 1972) ensuring at least a good start during the early germination stages which can be critical for seedling establishment, especially in soils low in nutrients.

2. EFFECTS OF MINERAL NUTRITION ON *PHASEOLUS VULGARIS* L.

Mineral Nutrition for the Market Crop

Beans grown for human consumption can be divided into two categories, those of which the pods are eaten, and those of which only the seeds are eaten. The French bean (*Phaseoulus vulgaris* L.) is grown for either use. For many years the pods were harvested by hand for the fresh market, but now they are grown on a larger scale and harvested mechanically, mainly for processing.

As every agricultural and horticultural crop, French beans require an adequate and balanced supply of nutrients. This is essential for the production of maximum, high quality yields. This supply of nutrients depends on many factors, such as climatic conditions, soil conditions and cultivation techniques. These are different for each part of the world and sometimes different within the same geographical area. Each country has developed its own fertilizer recommendations, not only according to the nutrient uptake by the plant itself, but also according to the soil analysis and to the results from long term research.

There is a vast amount of research work in each country for fertilizer application and the results vary according to the country and the area within the country. As a result of the continuity of the research, recommendations have been developed which are subject to changes according to the latest findings and according to the current developments in science and technology.

Experiments carried out by the Processors and Growers Research Organisation (PGRO) in England have determined the optimum ratio of the main nutrients, N, P and K for French beans cultivated for fresh pods (Ellis, 1970). The results from these experiments indicated that nitrogen was the most important nutrient, phosphorus was second and potassium was the least important.

The results, as far as nitrogen and potassium are concerned, are a reversal of earlier recommendations for the crop based on research in other countries. According to Ellis, the reason why French beans, which are a leguminous crop, respond to nitrogenous fertilizers is thought to be due to the absence of activity of associated root nodule bacteria capable of fixing nitrogen from the atmosphere. The lack of response to potassium by French beans may have been because the plants obtained sufficient from the soil reserves, or because potassium added to the soil does not become available to a crop with a relatively short growing season and a poor root system. In conclusion Ellis recommended 100 units nitrogen, 70 units phosphorus and 35 units potassium per acre as a base dressing. This recommendation may be modified according to the soil type and the previous crop. In the Pea and Bean Growing Handbook, published by PGRO (1975a) the optimum ratio of 3:2:1 of N:P:K is recommended as a result of their experimental work at the time of publishing, and the following Table 1 has been included as a guide to growers. Similar recommendations are made by the Advisory Services (ADAS) of the Ministry of Agriculture, Fisheries and Food (1973a).

TABLE 1 : THE MANURIAL REQUIREMENTS OF FRENCH BEANS IN UNITS PER ACRE

SOIL TYPE	N		P		K	
	Green	Dried	Green	Dried	Green	Dried
Sandy Clay Loams	135	100	90	67	45	33
Silts	115	80	76	43	38	27
Organic	100	60	67	40	33	20

(PGRO, 1975a)

Mineral Nutrition for Seed Production

It is easy for the grower to find fertilizer recommendations for the fresh crop, but the seed producer has difficulty in obtaining information. There are virtually no experimental results concerning the needs in nutrients for seed production of French beans. Personal communications with some seed companies confirm this. They do not give any fertilizer recommendation to the seed producer, who follows his own experience or applies the same fertilizer regime as for the fresh crop. This is unsatisfactory but because the requirements have not been investigated the fertilizer regimes for seed production may not be making the best use of resources.

Recently, due to the increasing interest in more research on factors affecting seed production and seed quality, a few research workers have examined the effects of the main nutrients and micronutrients on seed yield and quality of French beans.

Petkov (1975) grew beans in soil experiments and examined the effects of the main nutrients, nitrogen, phosphorus and potassium and the micronutrient molybdenum, on seed yield, quality and progeny performance, under irrigated and non-irrigated conditions. The treatments examined were, control (no fertilizers), molybdenum 100 g/ha, two levels of nitrogen 40 and 80 Kg/ha, two levels of phosphorus 40 and 80 Kg/ha, the four combinations between the levels of nitrogen and phosphorous and the combination nitrogen 80 Kg/ha, phosphorus 80 kG/ha and potassium 60 kG/ha. From this experiment he obtained twenty-two different seed lots corresponding to the eleven treatments under irrigated and non-irrigated conditions. The twenty-two seed lots were tested in the laboratory and the field for their quality and progeny performance. The results obtained indicated that the treatments with the combinations of all nutrients and the treatment with molybdenum under irrigated conditions gave more viable seeds, with higher germinating energy and higher vigour. He did not find any effect on the number of pods per plant resulting from the mother plant nutrition, but he observed a trend for an increase in the number of seeds per plant and in the seed size, from the following treatments:

1. N 80 Kg/ha, P 80 Kg/ha, K 60 Kg/ha
2. N 40 Kg/ha, P 80 Kg/ha
3. N 40 Kg/ha, P 80 Kg/ha
4. Mo 100 g/ha

The highest average yield for a three year period was obtained from seeds derived from plants which received the NPK and Mo treatments. In the first case the yield was 14% higher and in the second 11.5%. Similar work with beans has been done by Koinov and Petkov (1975a, 1975b). The results from their experiments confirmed those of Petkov's work and also indicated that the different fertilizer treatments affected the seed protein content but not the P, K, Ca or Fe contents.

According to Stoimenov (1970, 1974) bean seed treated with Mo as ammonium molybdate resulted in considerably higher yields and increased the bean seed Mo content from 0.08 - 0.28 mg/Kg dry weight in the untreated crop to 4.76 - 5.83 mg/Kg. Subsequently he demonstrated that seeds with an increased Mo content produced better and higher yielding plants than the control, and that the combined application of N and Mo had a beneficial effect on the protein content of the seed, and that phosphorus fertilization increased the effectiveness of Mo.

The beneficial effect of Mo on bean seed yield, nodule formation and seed protein content has been confirmed by Velcev and Georgiev (1970), Nicolov (1972, 1973) and Braga (1972). Singh and Mandal (1975) working with *Phaseolus mungo* L. demonstrated again the effects of molybdenum on seed yield and quality. They tested four treatments, 1st NPK alone, 2nd NPK with lime, 3rd NPK with Mo, 4th NPK with lime and Mo. Nitrogen at 25 Kg/ha, phosphorus at 60 Kg P_2O_5/ha and potassium 30 Kg K_2O/ha were applied as basal dressings in all treatments. Lime at 37 q/ha was added one month before sowing to raise the soil pH to 6.5 in the second and fourth treatments only. Molybdenum at 1 Kg Mo/ha as ammonium molybdate was applied to the soil, at sowing in the third and fourth treatments. The results indicated that the seed yield increased from the molybdenum and molybdenum with lime treatments. The 1000-grain weight increased by lime, molybdenum and molybdenum with lime treatments. There was no effect on the number of seeds per pod or on the length per pod. The ratio straw/grain was significantly lower under molybdenum and molybdenum with lime treatments. The authors did not examine the seed quality further, either by germination and other tests or determining the seed chemical composition.

Meagher *et al* (1952) working with French beans and peas attempted to demonstrate molybdenum deficiency symptoms in legumes, but they found it difficult because the seeds contain sufficient molybdenum to support the growth of several generations of plants. However, seed deficiency in this element gave poorer plants than normal seed in molybdenum deficient cultures.

The effects of molybdenum deficiency have been confirmed by Hewitt *et al* (1954). They also demonstrated copper and zinc deficiency symptoms on French beans and they showed that extreme deficiencies in these elements produce seed with reduced levels from the same elements.

Le Baron (1966) and Boawn *et al* (1969) were working with zinc deficiency in beans and its effects on seed quality. They concluded that zinc deficiency affects seed vigour indirectly, by delaying the maturity for up to 30 days. Since beans are grown in areas where the length of the growing season is marginal, this delay could result in seed maturation under unfavourable environmental conditions.

Montojos and Magalhaes (1971) also working with French beans examined the effects of nitrogen under varying solar radiation on plant growth and seed yield. They did not examine the effects of different amounts of nitrogen but different times of application. The total amount of nitrogen given was 66 Kg/ha and the treatments given were:
1st nitrogen in two applications 7 and 14 days after emergence;
2nd nitrogen in three applications 7, 14 and 21 days after emergence;
(each under high and low solar radiation conditions).
The results indicated that under low light conditions the application of nitrogen early in the growing period determined low rates of dry matter accumulation probably due to the disruption of the photo-synthesis-respiration balance that caused the lower leaves to die early and thus limiting plant growth. Three applications of nitrogen promoted the development of a larger leaf area but, more important, prevented the decline of the leaf area shortly after the period of

flowering allowing the plants to support increasing rates of dry matter production. Nitrogen applied in two applications determined a higher rate of dry matter accumulation under conditions of high solar radiation, as compared with the treatment of applying nitrogen in three applications. However, the higher growth rate observed in the treatment of high solar radiation - two nitrogen applications was negatively correlated with the final seed yield. Largest seed production was obtained when the nitrogen was applied three times during the first 21 days of the growing period. This treatment delayed leaf senescence and improved the photosynthetic capacity of the crop because of the increase in leaf area duration.

Ries (1971) examined the relationships in French beans between different seed protein levels and seed sizes with growth, seed yield and seed protein of the next generation. For this purpose he planted seeds of one white seeded cultivar of French beans at different locations and applied three nitrogen levels (0, 50 and 100 KgN/ha). These applications resulted in bean seed with different seed weights and protein content. The higher values for seed size and seed protein resulted from the application of either 50 or 100 Kg N/ha. Subsequent greenhouse studies with ungraded seed of these different phenotypes showed that both seedling size and protein per seedling were positively correlated with seed size and the quantity of protein per seed. Ries selected small and large seeds on a weight basis to study separately the importance of seed size and protein per seed. Again there was a correlation between protein content per seed and the size of plants for each size of seed. These results from the greenhouse performance have been supported by the performance of these different phenotypes in the field. Seedling size, yield and number of fruit were more highly correlated with protein per seed than with seed size. From these results Ries concluded that the alteration of nitrogen as a single factor in the mother plant environment was responsible for an increase in growth and yield of the next generation. Finally he stated that the results do not prove that bean growth and yield are highly dependent on seed protein, but they indicated that there is some factor in bean seed closely related to the nitrogen content, and increased by adding nitrogen to the growing plant, which increased the vigour and yield of beans.

In addition to the work described above the following points emphasise the importance of further investigation of seed nutrition:

1. The importance of seed quality in modern agriculture and especially in modern vegetable production.
2. The number of different factors which apparently affect seed vigour.
3. The lack of information concerning the effects of the environmental factors on seed production, during the mother plant growth and subsequent seed development.
4. The importance of legumes in all parts of the world as a valuable source of food.
5. The increasing cost of fertilizers.

It was decided to examine the influence of nitrogen, phosphorus, potassium and molybdenum on seed production of *Phaseolus vulgaris* L. It is desirable that the seed producer knows the optimum levels of nutrients for the maximum seed yield, and which levels provide the maximum seed quality. The question arises as to whether these levels are the same for both seed yield and quality. The correlation between nutrient level and seed yield and seed quality may be positive or negative. In addition it is necessary to understand which of the main nutrients play a significant role in seed production.

The present work is intended to attempt to answer these and related questions.

3. EFFECTS OF HARVEST STAGES AND FRUIT POSITION ON THE MOTHER PLANT ON SEED YIELD AND QUALITY

The seed producer has to decide the time to harvest a seed crop. The decision takes into account past and expected weather, the availability of machinery and labour, as well as the state of maturity of the crop (Austin, 1972). However, the estimation of seed maturity is not straightforward. Thus seed maturity, another important factor thought to affect seed vigour, has been the subject of numerous studies. Many papers on seed maturity and its effects on seed vigour have been reviewed by Heydecker (1972), Austin (1972), Pollock and Roos (1972), Perry (1972, 1976), Bradnock (1975) and Copeland (1976).

Maturation is a process which takes place during the later part of the life of seed while still on the mother plant. During this process very important morphological and physiological changes occur (Austin, 1972). Seeds which have completed these changes are considered as fully mature seeds. Pollock and Roos made the general conclusion, from the literature on seed maturity, that the more mature a seed is when harvested the greater its vigour and therefore the better the seedling establishment. Attempts have been made by different workers to correlate seed maturity with measurable seed characteristics, such as seed dry weight and seed moisture. As a result, seed moisture content is often used as an index of seed maturity and therefore of the time of harvest, and no further increase in dry weight is used to define full maturity (Austin, 1972; Copeland, 1976). However, a criticism is that after harvest each seed lot can consist of seeds removed from the mother plant at different stages of maturity, and therefore the seed lot is a population of individual seeds with a range of vigour levels.

This variability begins with the sequence of floral initiation and opening. After fertilization, seeds borne on different parts of the mother plant may be exposed to different sets of environmental conditions. The causes of variability in seed vigour associated with seed maturity differ according to the growth habit of the plant (Pollock and Roos, 1972). It can be concluded that the position of the fruit on the mother plant plays an important role in variability of seed maturity within a seed lot and therefore in the stage of harvesting.

Borthwick (1931) found that the umbels of carrots are formed terminally on branches and denoted the umbels in the order in which they were formed. Anthesis of each umbel is completed before it begins again on the next. Flowering on the entire carrot plant occurs as a series of periodic waves. Borthwick examined the germination of seed from different umbels and obtained the highest percentage of germination from seed of the first umbel. This highest percentage values was 73%

and started to decline with subsequent umbels, each showing a lower germination than the previous one. For example, the germination percentage was found to be 67% and 54% for seed from 2nd and 3rd order umbels respectively. Borthwick's findings on carrots have been confirmed by Hawthorn *et al* (1962).

Austin and Longden (1967b) harvested carrot seed on eight stages and the seeds from each harvest separated into four sizes by round-holed sieves. On examining the germination of the seed lots they found that the germination percentage increased with increasing seed size. Late harvested, mature seed of a given size generally had a higher percentage germination than less mature but otherwise similar seed. They confirmed these results with field trials. The increase of germination percentage and field performance with the increase of seed maturity within the same seed size was more marked in the smaller size grades, which contained the seed from the higher order umbels flowering later than the primary umbels.

Similar work with carrot and celery seeds has been done more recently by Thomas *et al* (1978). Carrot seeds harvested from primary and secondary umbels in two stages of maturity, 'immature' and 'mature', and celery seeds harvested from four umbel positions on mother plants. The seed lots obtained were examined for germination at different temperatures in the laboratory and for emergence. The results indicated that the position at which a seed is produced on the mother plant can markedly affect its size, germination characteristics and the size of the resulting seedling. In both species, the lowest germination percentage and seedling emergence were obtained from seeds produced on primary umbels, and in carrots these effects were more pronounced with 'immature' than with 'mature' seeds. In carrots the percentage of germination from 'mature' seeds was above 90% in the temperature range 5-25°C and from 'immature' seeds was around 80% for seeds from the primary umbels and around 90% for seeds from secondary umbels. Similarly in celery, seeds from tertiary and quartenary umbels showed a germination percentage of 94% and 82% compared with 50% from primary umbels. In carrots there was evidence that differences in germination between umbel order were positively correlated to differences in mean length of seed embryo. In celery, umbel order affected the dormancy mechanism of the seeds. Thomas *et al* also found that seeds from primary umbels were larger than from secondary umbels and produced heavier seedlings, but the variability in the size of seedlings produced from secondary umbel seeds was greater than from primary umbel seeds.

Matthews (1973), examining the effect of harvest time on pea seed quality, harvested the seeds at eight stages and from three different positions on the mother plant at each stage. Although he considered the seed from the three positions as of different ages, his results provided evidence that within each harvest lot the seed quality was affected by the pod position on the plant, especially in the early harvests. For example the percentage viability in seed from the lower part of the plant started from 40% in the first harvest and reached a maximum around 90% in the fourth harvest following a slight decline in the other harvests. In contrast, seed from the upper part of the plant had a 10% viability in the first harvest and reached a maximum around 80% with the last harvest.

Matthew's work, which considers the seeds from different positions on the mother plant as seeds of different age, leads to the suggestion that the age of seed plays the most important role on seed maturation and furthermore that if seed from later flowers is left on the plant until a later harvest then the seed quality will be similar to seed from earlier flowering.

In contrast Thomas *et al* demonstrated in their work that the position of the seed on the plant affects the seed quality even in mature stages. So not only the age of seed (i.e. days from flowering or fertilization) affects the seed quality but the position of the seed on the mother plant, or factors related to the seed position, affect the seed quality.

Pollock and Roos (1972) suggested that perhaps seasonal environmental changes overlaid by a highly irregular series of day-to-day weather fluctuations, interact with the sequence of anthesis on the different parts of the plant and have as a result seed with differing quality from the same plant. Furthermore, they suggested that the first seeds in a developmental sequence may have a competitive advantage over later seeds formed in the sequence.

Soffer and Smith (1974a) with their work on lettuce demonstrated that lettuce plants showed four definite flowering peaks over a 70-day period. Seed produced from flowers opening during the first two flowering peaks were heavier (1.4 mg/seed maximum) than those produced later (0.9 - 1.0 mg/seed minimum). However, seed weight has been shown to have positive correlation with seed vigour (Smith *et al*, 1973).

4. EFFECTS OF HARVEST STAGES AND POD POSITION ON THE MOTHER PLANT FOR SEED PRODUCTION OF *PHASEOLUS VULGARIS* L.

Beans are ready for harvesting when the earlier developed pods are dry and most of the remainder have turned yellow. Despite this criteria, the determination of the ideal harvest time is not easy because if there is adequate soil moisture the beans tend to set pods until relatively late. There is therefore the danger of either harvesting the crop early, resulting in the percentage of immature seeds being quite high, or of harvesting late, when too many of the pods are dry, resulting in heavy losses from 'shattering'.

Bean seeds are commercially harvested mechanically in a once over operation, or by hand if in small plots. The plants are cut about 5 cm below the surface of the soil, usually early in the morning while the dew is still present, to prevent 'shattering'. The bean plants require one or two weeks to dry further, after which they are threshed by machine or hand (Hawthorn and Pollard, 1954).

Several workers examined the effects of harvesting stages on bean seed production and have attempted to determine the stage at which maximum yield and quality will be achieved. Smith (1955) in his experiments with pink beans studied the effects of dates of harvest operations (cutting and threshing) on seed yield and quality. He made three cuts, the first a week before they were ripe; the second when ripe; and the third a week after optimum ripening (he called this the 'over-ripe stage'). The plants cut on any given date were threshed at three different times, thresh 1 - one week; thresh 2 - two weeks;

and thresh 3 - three weeks after cutting. Smith explains that the first cutting had to be estimated as nearly as possible to a week before the beans were ripe, and he based this estimation on the colour change around the hilum. In order to obtain the minimum exposure time another treatment, called 'thresh 0', was made by taking a sample of beans from the guard rows at each cutting date and drying it artificially. As a result he obtained 12 seed lots, which were examined for seed yield, seed size (the weight in g of 100 beans), and the percentage of brown beans which are a problem in pink beans. The results indicated that the yield was affected by the cutting dates and not by the threshing dates. He found an average reduction of 318 pounds per acre between normal cutting dates and the early cutting dates. The seed size was reduced by the early cutting. Differences between threshing dates were probably due to differences in moisture content. In one of the locations used, the cut 1, thresh 0 treatment had the smallest seed, indicating that the beans had become drier and hence lighter under artificial drying than those cuts at the same time and cured in the field; another possiblity is that the bean plants which were cut and dried immediately had less time to translocate material from the plant. Further evidence that moisture content had an influence on the weight of the beans is given by comparing all plots cut early, the seed size was smallest in those artificially dried (26.6 g / 100 seeds); and largest in those exposed one week (30.7 g / 100 seeds). The average seed size in cut 2 was 31.6 g / 100 seeds and in cut 3, 31.4 g / 100 seeds; in thresh 0, 30.3 g / 100 seeds; and in threshes 1,2,3, 31.6 / 100 seeds. However, Smith did not examine the effects of different treatments on seed germination and vigour.

Inoue and Suzuki (1962), studied the effects of maturity and after ripening on the germinability of seeds, using a dwarf cultivar of French beans. They harvested the pods 15,20,30 and 35 days after anthesis. The seed lots were subdivided and then after-ripened for 5,10,15 and 20 days. Both dates of harvest and dates of after ripening significantly affected the germination. Seeds harvested 15 days after anthesis did not germinate at all, and seeds harvested 35 days after anthesis showed almost 100% germination. But seed harvested 15 days after anthesis germinated to some degree by the fifth day after ripening and almost 100% by the 20th day from ripening. Seeds harvested 20 days after anthesis which would show less than 10% germination in fresh state reached 100% germination by 10 days after ripening. Another conclusion made by Inoue and Suzuki is that there was the tendency for seed which were harvested early and after ripened, had better germinability than fresh seeds, although the total number of days from anthesis was the same.

Rena and Vieira (1971) in six experiments with two cultivars of French beans studied seed yield and quality in four different stages of maturity. In the very early harvest 70-100% of the pods were green, but containing well developed seeds. In the early harvest about 50% of the pods were coloured, 30% green and 20% dry. In the normal harvest 70-90% of the pods were dry, and the rest coloured. In the late harvest all pods were dry. According to their results the very early harvest resulted in a tendency to decrease yield, germination percentage and to produce smaller seeds of low quality. The yield and seed quality were similar in the other three harvests. The stage of maturity, as indicated by harvest time, had little effect upon the protein content of the seed.

In similar trials Monteiro and Vieira (1972), examined the effects of stages of maturity on thirteen dry bean cultivars. The seeds were harvested when they had reached an average of 60%, 50%, 30% and 15% moisture. In the sample with 60% moisture, 60-80% of the pods were green, 20-40% coloured and 0-15% dry; the leaves were green and without leaf drop. In the harvest with 50% moisture, there was an almost equal distribution of green, coloured and dry pods. The majority of the leaves were yellow, but they had not started to drop. In the harvest with 30% moisture, 65-85% of the pods were dry, the remainder green or coloured; all the leaves were yellow and many of them had dropped. In the harvest with 15% moisture, all pods were dry and the bean plants had dropped all their leaves. Only the earliest harvest with 60% seed moisture had decreased yield and seed weight but germination was not affected. The effect of harvest time on the percentage of abnormal seedlings was not significant, with the exception of the cultivar 'Manteigao Fosco 11' which had a marked increase in the number of abnormal seedlings when harvested at 60% moisture.

Significant reductions in germination and seedling vigour were observed by Wijandi and Copeland (1974) in bean seed harvested prior to complete maturity. The seed was hand harvested at 116 days from sowing and the pods grouped into three maturity classes on the basis of colour: pale-green, yellow and brown. The pods were naturally dried and hand threshed, the resulting seeds were graded and tested for germination and seedling vigour. The results indicated that significant increases in both germination and seedling vigour expressed as seedling height at 11 days, were obtained by harvesting seed at full maturity (brown pods) rather than at earlier stages. The percentage of germination in seed from pale-green pods was 92.75% and from brown 99.00% and the seedling height was 11.38 cm and 15.57 cm respectively. The authors also stated that, to avoid losses from 'shattering' the seed crop was pulled and windrowed prior to complete seed maturity. Due to the natural variation in plant maturity, some plants were pulled while many pods were in the pale-green and green stages. Wijandi and Copeland's studies indicated that this procedure of harvesting may result in significant losses of vigour.

In their recent work Silva, Vieira and Sediyama (1975a), correlated their observations and studies on seed maturity, with the ovule fertilization. They tagged flower buds and subsequently harvested the pods after ovule fertilization at 48 hour intervals during 60 days. Ovule fertilization was considered to take place during flower opening. They found that seed maturity takes place from 40 to 54 days after ovule fertilization, and during this period the seeds have 30 to 40% moisture content. Their results indicated that when tested immediately after harvest the seeds showed some germination 20 days after ovule fertilization and reached a maximum after 38 days but previously dried seed germinated 30 days after fertilization, attaining a maximum after 34 days. The results for seed vigour showed that 30 days after ovule fertilization, the seeds had low vigour but after 38 days they reached the maximum. However, considerable vigour loss started 50 days after fertilization.

Following these observations, Silva, Vieira and Sediyama (1975b) tried to determine the optimal harvest time for French beans on the basis of the physiological quality of the seeds. They harvested the seeds at 2 day interals starting from 72 days after emergence and finishing at 102 days, i.e. harvesting stages totally 16. At each harvest the plants from the experimental row were pulled up and the pods were picked. The physiological quality of the seeds was determined immediately after harvest and 30 days after drying. The methods used for assessing seed quality were the ISTA germination tests and the accelerated ageing test for vigour determination. The results indicated that the maximum physiological quality was established when the seeds were harvested 86 to 90 days after seed emergence. The germination percentage from the germination test was 90-95% and 70-75% from the accelerated ageing test. The seed quality was lower in seed harvested before the 86 days and started declining after 90 days. For example the accelerated ageing test gave less than 5% germination for seed harvested at 72 days after emergence and 20% for seed harvested at 102 days. The results from seed left to dry indicated that the maximum physiological quality was established when the seeds were harvested 84-94 days after emergence. For such seed the germination percentage from the accelerated ageing test was 65-75%. The authors accepted that the commercial harvest time (90 days after sowing) in the same area coincides with that of maximum seed vigour. They subsequently examined the field performance of the seed produced from the 16 harvesting dates. From the results obtained they found that seeds harvested early required greater time to emerge when sown in soil, than those from later harvests.

The initial and final stands were both affected from the stage of seed maturity, and thus the laboratory results have been confirmed. However, the treatments did not show any significant effect on the seed production of the progeny.

The majority of the work described above agrees that there is variability in seed maturity within the same seed lot representing one harvest stage.

Silva *et al* (1975b) stated that the flowering of the bean plant takes a certain number of days which varies according to environmental conditions, and for this reason, in each harvest time which they studied, seeds of different stages of maturity and seed vigour were together.

Ojehomon (1966) studied the sequence of flower opening and of floral initiation in French beans. He found that irrespective of the number of leaves on the main stem, the first flowers to open and set fruits on the plant occur directly on the main stem, in the axil of the uppermost leaf. The next flowers to open are those lowest on the terminal inflorescence of the main stem. Thereafter, many flowers open simultaneously at different nodes. The same sequence has been found in the flower initiation. The first floral primordium formed on the plant is in the axil of the uppermost leaf. The second floral primordia to be formed is the lowest one on the terminal inflorescence, and so on. Ojehomon also found that the floral initiation is affected by the temperature at which the plant is grown. At 25°C the first floral bud primordium was initiated two days before the second one.

This time difference increased to more than fifteen days at 15°C. No floral initiation was observed at 10°C.

Wivutvongvana and Mack (1974) with similar work on French beans confirmed Ojehomon's findings. They demonstrated that the first flowers to open were 1 or 2 flowers of the triad at the uppermost leaf, which they classified in the first group of opened flowers. The second group were those of the first triad of the main terminal raceme, those of triads of non-leaf branches and those of one-leaf branches. The third group of flowers opened at the first node and nodes with two or more branches.

It may be concluded from all the work described above that at harvest time the seed lot consists of individual seeds of a range of vigours, due to variations in flower initiation and flower opening. It is also well known that the flowering process takes place in successive waves and that it is affected by the climatic conditions, especially temperature. There is however, no information as to how much the seed coming from each flower group, and position on the plant, affects the seed yield and quality.

C. MATERIALS AND METHODS

1. MOTHER PLANT NUTRITION EXPERIMENTS

Experiment No. I

In the first experiment the effects of different levels of nitrogen, phosphorus, potassium and molybdenum on seed yield and quality of French beans (*Phaseolus vulgaris* L.) were examined. The experiment was conducted during the spring and summer of 1977 in an East-West orientated, heated glasshouse.

The cultivar 'Cascade' was chosen because it is suitable not only for the fresh market but for the processing industry, and according to PGRO cultivar trials (PGRO, 1975b) it is one of the most popular and well-established processing cultivars in England.

A compost based on GCRI potting media (Table 2) was used, in order to provide the plants with uniform substrate, having a high total porosity, satisfactory water retention and an adequate air capacity (Bunt, 1976). This loamless compost has been found to be suitable for research work as the peat is relatively sterile and very low in nutrients, enabling different combinations of nutrients to be added (Flegmann and George, 1975). The plants were grown in plastic pots of 6ℓ capacity.

TABLE 2 : THE GCRI POTTING COMPOST I COMPOSITION

75% by volume sphagnum peat.

25% by volume fine, lime-free sand.

To this mixture is added (per cubic metre):

1. 0.4 Kg ammonium nitrate
2. 1,5 Kg superphosphate
3. 0.75 Kg potassium nitrate
4. 2.25 Kg ground limestone
5. 2.25 Kg dolomite limestone
6. 0.400 Kg fritted trace elements 253A*

This gives an added nutrient content of:

N	P	K	
230	120	290	mg/l.

*Composition of frit No. 253A

B	2%	Mn	4.90%
Cu	2%	Mo	0.13%
Fe	12.25%	Zn	4%

(Bunt, 1976)

The following nutrient levels were selected:

N_1 : 0.60 g	N/pot	K_1 : 0.60 g	K_2O/pot
N_2 : 1.20 g	N/pot	K_2 : 1.20 g	K_2O/pot
N_3 : 1.80 g	N/pot	K_3 : 1.80 g	K_2O/pot
P_1 : 0.15 g	P_2O_5/pot	M_1 : 3 mg	Mo/pot
P_2 : 0.45 g	P_2O_5/pot	M_2 : 18 mg	Mo/pot
P_3 : 0.75 g	P_2O_5/pot		

The following points were taken into account when choosing these nutrient levels:

1. The most recent research and fertilizer recommendations reported in the literature.

2. The amounts of nutrients to be removed from the soil by the crop, which in the case of a normal bean crop are 85 Kg N/ha, 21 Kg P_2O_5/ha, and 87 Kg K_2O/ha (Anon, 1976).

3. The nutrients lost by leaching. Bunt (1976) found that these losses for compost consisting of 3 parts peat, 1 part sand are 85% for NH_4-N, 87% for NO_3-N, 60% for P, and 70% for K of the amounts initially added.

The treatements in this experiment were all possible combinations of the selected nutrient levels (e.g. 3N x 3P x 3K x 2 Mo = 54 treatments) (Table 3). They were arranged in a factorial randomised block design of four replications. The fertilizers used in the experiment were ammonium sulphate (21% N), superphosphate (20% P_2O_5), potassium sulphate (48% K_2O) and ammonium molybdate (54% Mo). The amount of fertilizer for each nutrient level was calculated and one quarter of each of the main nutrients and the total amount of ammonium molybdate were added as a base dressing. The remaining amounts were given in three top dressings from seedling emergence to anthesis (Table 4).

TABLE 3 : TREATMENTS OF EXPERIMENT No. 1

No. of Treat.	Treatment	No. of Treat.	Treatment
1	N_1 P_1 K_1 M_1	28	N_2 P_2 K_2 M_2
2	M_2	29	K_3 M_1
3	K_2 M_1	30	M_2
4	M_2	31	P_3 K_1 M_1
5	K_3 M_1	32	M_2
6	M_2	33	K_2 M_1
7	P_2 K_1 M_1	34	M_2
8	M_2	35	K_3 M_1
9	K_2 M_1	36	M_2
10	M_2	37	N_3 P_1 K_1 M_1
11	K_3 M_1	38	M_2
12	M_2	39	K_2 M_1
13	P_3 K_1 M_1	40	M_2
14	M_2	41	K_3 M_1
15	K_2 M_1	42	M_2
16	M_2	43	P_2 K_1 M_1
17	K_3 M_1	44	M_2
18	M_2	45	K_2 M_1
19	N_2 P_1 K_1 M_1	46	M_2
20	M_2	47	K_3 M_1
21	K_2 M_1	48	M_2
22	M_2	49	P_3 K_1 M_1
23	K_3 M_1	50	M_2
24	M_2	51	K_2 M_1
25	P_2 K_1 M_1	52	M_2
26	M_2	53	K_3 M_1
27	K_2 M_1	54	M_2

TABLE 4 : AMOUNT OF FERTILIZERS USED PER NUTRIENT LEVEL AND PER DRESSING IN EXPERIMENT No. 1

Nutrient Levels	Fertilizer	Total amount of Fert. g/pot	Dressings g/pot			
			Base	1st top	2nd top	3rd top
N_1	Ammonium	2.857	0.714	0.714	0.714	0.714
N_2	Sulphate	5.714	1.428	1.428	1.428	1.428
N_3	21% N	8.571	2.143	2.143	2.143	2.143
P_1	Superphosphate	0.750	0.187	0.187	0.187	0.189
P_2	20%	2.250	0.563	0.563	0.562	0.562
P_3	P_2O_5	3.750	0.938	0.938	0.937	0.937
K_1	Potassium	1.250	0.313	0.313	0.312	0.312
K_2	sulphate	2.500	0.625	0.625	0.625	0.625
K_3	48% K_2O	3.750	0.938	0.938	0.937	0.937
M_1	Ammon. molyb.	0.00 mg/pot	0.00	-	-	-
M_2	54% Mo	28.00 mg/pot	28.00 mg	-	-	-

Note: In the first level of Mo (M_1) no ammonium molybdate was added because the compost already contained 3 mg Mo per pot derived from the Frit 253A. In the second level of Mo (M_2) 28 mg ammonium molybdate was added containing 15 mg Mo. This amount, together with the 3 mg from the Frit 253A supplied the second level of Mo (M_2 = 18 mg)

Compost Preparation

Fifty-four different composts were prepared, corresponding to each of the fifty-four treatments. To formulate each compost, the peat and sand were first mixed thoroughly. The ground limestone, dolomite limestone and Frit No. 253A were then added (Table 2). The materials were then mixed again and finally the quantities of the base dressing were added and the mixture was turned twice (Table 4). Only the N, P, K were added at this stage. Molybdenum was added in the pots, after mixing and before sowing, as a liquid feed. After mixing a 10 day period was allowed for neutralization.

Cultural Details

The glasshouse temperature was controlled at 15°C for the night and at 25°C for the day. The ventilation automatically opened when the temperature was above 25°C. The maximum and minimum temperatures recorded each day during the experiment are given in Appendix 1.

Three seeds were sown per pot and the resulting seedlings were left to establish. The seedlings were subsequently thinned to one per pot when the primary simple leaves were well formed.

The crop programme was as follows:

Seeds sown	15 April 1977	2nd top dressing	20 May 1977
Emergence	23-27 April 1977	3rd top dressing	3 June 1977
Thinning	1 May 1977	picking first pods	29 July 1977
1st top dressing	6 May 1977	picking last pods	28 Aug. 1977

The fertilizer mixtures for the top dressings sprinkled over the surface of the composts and watered in. The compost was visually checked regularly for water requirement. Uniform watering was achieved by timing the water flow from the hose with a stop-watch. Preliminary observations have been made to estimate the amount of water needed for a 6 lit. pot, in order to avoid excess water and to minimise leaching. According to the Wessex Water Authority (1978) the quality of irrigation water used was as in Table 5.

During plant growth resmethrin was used to control whiteflies *(Trialeurodes vaporariorum)*, and benlate to control botrytis *(Botrytis cinerea)* when necessary. Whiteflies were one of the most serious and persistent pests, and were very difficult to control, because most insecticides were effective only against the adult forms (MAFF, 1973b).

The pods were harvested in successive harvests at three day intervals. At each harvest the pods which were dry or had started to dry were picked, in order to ensure that the harvested seeds were of uniform maturity. After each harvest the seeds were left for 30 days on laboratory benches. The seeds were then extracted from the pods and again they were left for a further 15 days to reduce excess moisture. After this period the seeds were stored in paper bags, under laboratory conditions.

During the plant growth the following observations were made:

1. The number of new flowers per plant every two days in two of the four replications.

2. The number of pods per plant and per harvest.

3. The number of seeds per pod and per plant.

TABLE 5 : IRRIGATION WATER QUALITY

Treatment			Maximum	Minimum	Average	No. of Samples
pH			7.6	7.1	7.39	32
Conductivity			770.0	530.0	702.0	32
Ammoniacal	N	in ppm	0.09	0.01	0.025	32
Nitrite	N	in ppm	0.02	0.01	0.011	32
Total oxidised	N	in ppm	6.16	2.48	4.33	31
Total organic	N	in ppm	0.05	0.05	0.05	3
Onthophosphate	P	in ppm	0.07	0.01	0.018	32
Alkalinity	$CaCO_3$	in ppm	250.0	205.0	229.6	3
Total phosphate	P	in ppm	0.05	0.05	0.05	3
Potassium		in ppm	3.0	1.8	2.4	2
Manganese		in ppm	0.005	0.002	0.0035	2

4. The seed yield per plant.

5. The total length of the main stem, secondary and tertiary branches after harvesting.

From these observations the following parameters were calculated:

1. Total number of flowers per plant.

2. Total number of pods per plant.

3. Percentage setting.

4. Mean time to harvest, using the formula:

$$\text{Mean time to harvest} = \frac{P_1\ T_1 + P_2\ T_2 + \ldots + P_n\ T_n}{P_1 + P_2 + \ldots + P_n}$$

where P_1 = number of pods harvested at time T_1.

P_2 = number of pods harvested at time T_2 and so on.

5. Number of seeds per plant.

6. Number of seeds per pod.

7. Total seed yield per plant.

8. Total length of the main stem.

9. Total length of secondary branches.

No symptoms of nutrient deficiencies or toxicities were observed during the experiment.

Tests For Seed Quality

1st Test : Seed Size Determination

Seed size is internationally accepted as one of the main components of seed quality (Perry, 1978) and the 'thousand seed weight' of seed lots, determined according to the ISTA Rules for Seed Testing (ISTA, 1976), is often provided as information at the time of sale. For these reasons it was decided to determine it in all the experiments. The seed size in this experiment was determined, after seed drying and during the storage in the paper bags, in two different ways:

(a) The total seed yield per plant divided into the total number of seeds per plant. The result was the mean weight per seed in g.

(b) Four samples of 25 seeds each, from each treatment were weighed and the 100 seed weight was calculated.

The sample size had to be reduced to 25 seeds because of the low yield in some of the treatments. For the same reason all the treatments included the lowest level of phosphorus (P_1) were excluded from this determination.

2nd Test : Germination

This standard seed quality test was used to evaluate all experimental seed material produced. The germination test is internationally accepted and allows the germination percentage of a given seed lot to be determined according to the International Rules for Seed Testing (ISTA, 1976). This test also allows other parameters, such as rate and uniformity of germination to be measured. These and the time to

50% germination can be an expression of seed vigour (Heydecker, 1969; McDonald, 1975).

The environmental conditions for this test were according to ISTA specifications, but in some cases the sample number was modified because of relatively low seed yield in some of the treatments. For the same reason the treatments which included the lowest level of phosphorus (P_1) were excluded from this test.

Thus 36 treatments were tested with samples of 25 seeds each, randomly selected, and replicated three times. A randomised block design was used with factorial arrangement. The 25 seeds from each treatment were sown 2.5 cm deep in plastic trays, size 15 cm x 21 cm x 5 cm, and containing Levington Universal Compost (Tonkin, 1978). After sowing the trays were watered to field capacity and placed in a growth cabinet at a constant temperature of 20°C and not less than 95% relative humidity. Light from fluorescent lamps was provided for 12 hours in each 24 hour cycle. The germinating seeds were counted daily until the ninth day from sowing. After the ninth day the seedlings were classified as normal or abnormal according to the ISTA rules. From the observations made during the germination test the following parameters were calculated:

1. The percentage of germination from the number of normal seedlings.

2. The coefficient of germination rate (CRG) or coefficient of velocity of germination (CVG) using Kotowski's formula:

$$CRG = \frac{\Sigma n}{\Sigma (Dn)} : 100$$

where n = the number of seeds germinating on Day D)

D = the number of day, counted from the day of sowing, which is 0. (Heydecker, 1973).

3. The seedling mean dry weight, which was determined by dividing the total dry weight by the number of seedlings.

To find the total dry weight, the normal seedlings were dried in an oven at 100°C for 48 hours. Before drying the cotyledons were removed from the seedlings. This was done in order to estimate more accurately the seedling vigour expressed as the total of new tissues resulting from a possible given utilization rate (Perry, 1979 - Personal communication).

3rd Test : Seedling Evaluation

Although it is acceptable that the rate of germination, speed of germination and similar parameters can express the seed vigour to some extent and they can be measured during germination tests, thus saving time, they are not always an essential component of seed and seedling vigour. Heydecker (1972) in his review article on vigour, mentioned some cases in which the high speed of germination does not mean high vigour: e.g. seeds which have matured particularly well may imbibe, and therefore germinate slower than those less fortunate; seeds infected with seed-borne pathogens may occasionally be stimulated into earlier germination than healthier ones, and seeds may be slow to germinate because they are still partly dormant.

For these reasons, another test was carried out, suitable for determining seed and seedling vigour. The same author suggested that a test based on early seedling growth will be in favour, especially for agronomic purposes. In this type of test three components are assessed: (1) the rate of germination; (2) the rate of growth after germination; and (3) the integrity and normality of the seedlings. Such tests have already been introduced by Perry (1969b) for peas, and by Tonkin (1969) for several other species, including French beans. These tests have been accepted by the International Seed Testing Association (Wellington, 1970). Tonkin's glasshouse test has been chosen for all the experiments reported in this research.

According to this test, samples from the different treatments of 25 seeds each were sown 2.5 cm deep in plastic trays, size 15 cm x 21 cm x 5 cm, containing Levington Universal compost. The trays with the seeds were kept in a glasshouse for seed emergence and seedling development. The test was continued until the first trifoliate leaf was fully developed on the majority of seedlings. During this test all the observations were made as for the germination test. At the end of the test the seedlings were harvested and the normal ones were classified into three categories, according to the size of the largest. To make this classification the stem of each seedling was weighed and recorded. The weight of the largest seedling per treatment was found and from these the mean weight of the largest in each replicate was determined. After that the seedlings from each treatment with a weight half or more of that of the mean largest seedling were classified as normal vigorous seedlings, seedlings having a weight between quarter and half of the weight of the largest were classified as normal weak seedlings and seedlings having weight less than quarter of the largest were classed as abnormal or very weak seedlings. 36 treatments were examined (treatments with P_1 were excluded) in 4 replications, and the following parameters were measured:

1. Percentage of emerged seedlings, as a percentage of normal seedlings.
2. Rate of emergence as in the germination test.
3. Mean dry seedling weight as in the germination test.
4. Percentage of vigorous seedlings, weak seedlings and very weak seedlings.

Experiment No. 2

Following the results of the first experiment, two further experiments were planned (Experiment No.2 and Experiment No.3). In Experiment No.2 the main nutrients: nitrogen, phosphorus and potassium were again examined, using levels different from those in Experiment No.1. In Experiment No.3 nitrogen and molybdenum were examined in more detail.

Experiment No.2 was conducted in the spring and summer of 1978 in the same glasshouse as Experiment No.1 and using the same cultivar 'Cascade'. Also the size of the plastic pots was the same and the compost was again based on GCRI potting media.

The nutrient levels were chosen taking into account the results from Experiment No.1 and were as follows:

N_1 : 0.3 g N/pot	N_2 : 1.2 g N/pot	N_3 : 2.1 g N/pot
P_1 : 0.3 g P_2O_5/pot	P_2 : 1.2 g P_2O_5/pot	P_3 : 2.1 g P_2O_5/pot
K_1 : 0.3 g K_2O/pot	K_2 : 1.2 g K_2O/pot	K_3 : 2.1 g K_2O/pot

The treatments in the experiments were all possible combinations of the selected nutrient levels (e.g 3N x 3P x 3K = 27 treatments) and were arranged in a factorial randomised block design of eight replications. The increase in the number of replications was to obtain more seed per treatment for subsequent seed testing. The fertilizers used in the experiment were, ammonium nitrate (35% N), superphosphate (18-20% P_2O_5) and potassium sulphate (48% K_2O). One-fifth of phosphorus and potassium was given as base dressing and the remaining amounts were applied with the total amount of nitrogen as top dressings, starting one week after seed emergence (Table 6).

TABLE 6 : TOTAL AMOUNT OF NUTRIENTS PER TREATMENT AND BASE DRESSING IN EXPERIMENT No. 2

No. of Treat-ments	Treatments			Total amount of Nutrients. g/pot			Base Dressing g/pot				Remaining Amounts For Top Dressings. g/pot		
							Amount of Nutrients		Amount of Fertilizers				
				N	P_2O_5	K_2O	P_2O_5	K_2O	Super-phos.	Pot. Sul.	N	P_2O_5	K_2O
1	N_1	P_1	K_1	0.3	0.3	0.3	0.06	0.06	0.30	0.125	0.3	0.24	0.24
2			K_2	0.3	0.3	1.2	0.06	0.24	0.30	0.500	0.3	0.24	0.96
3			K_3	0.3	0.3	2.1	0.06	0.42	0.30	0.875	0.3	0.24	1.68
4		P_2	K_1	0.3	1.2	0.3	0.24	0.06	1.20	0.125	0.3	0.96	0.24
5			K_2	0.3	1.2	1.2	0.24	0.24	1.20	0.500	0.3	0.96	0.96
6			K_3	0.3	1.2	2.1	0.24	0.42	1.20	0.875	0.3	0.96	1.68
7		P_3	K_1	0.3	2.1	0.3	0.42	0.06	2.10	0.125	0.3	1.68	0.24
8			K_2	0.3	2.1	1.2	0.42	0.24	2.10	0.500	0.3	1.68	0.96
9			K_3	0.3	2.1	2.1	0.42	0.42	2.10	0.875	0.3	1.68	1.68
10	N_2	P_1	K_1	1.2	0.3	0.3	0.06	0.06	0.30	0.125	1.2	0.24	0.24
11			K_2	1.2	0.3	1.2	0.06	0.24	0.30	0.500	1.2	0.24	0.96
12			K_3	1.2	0.3	2.1	0.06	0.42	0.30	0.875	1.2	0.24	1.68
13		P_2	K_1	1.2	1.2	0.3	0.24	0.06	1.20	0.125	1.2	0.96	0.24
14			K_2	1.2	1.2	1.2	0.24	0.24	1.20	0.500	1.2	0.96	0.96
15			K_3	1.2	1.2	2.1	0.24	0.42	1.20	0.875	1.2	0.96	1.68
16		P_3	K_1	1.2	2.1	0.3	0.42	0.06	2.10	0.125	1.2	1.68	0.24
17			K_2	1.2	2.1	1.2	0.42	0.24	2.10	0.500	1.2	1.68	0.96
18			K_3	1.2	2.1	2.1	0.42	0.42	2.10	0.875	1.2	1.68	1.68
19	N_3	P_1	K_1	2.1	0.3	0.3	0.06	0.06	0.30	0.125	2.1	0.24	0.24
20			K_2	2.1	0.3	1.2	0.06	0.24	0.30	0.500	2.1	0.24	0.96
21			K_3	2.1	0.3	2.1	0.06	0.42	0.30	0.875	2.1	0.24	1.68
22		P_2	K_1	2.1	1.2	0.3	0.24	0.06	1.20	0.125	2.1	0.96	0.24
23			K_2	2.1	1.2	1.2	0.24	0.24	1.20	0.500	2.1	0.96	0.96
24			K_3	2.1	1.2	2.1	0.24	0.42	1.20	0.875	2.1	0.96	1.68
25		P_3	K_1	2.1	2.1	0.3	0.42	0.06	2.10	0.125	2.1	1.68	0.24
26			K_2	2.1	2.1	1.2	0.42	0.24	2.10	0.500	2.1	1.68	0.96
27			K_3	2.1	2.1	2.1	0.42	0.42	2.10	0.875	2.1	1.68	1.68

The required amount of phosphorus for the top dressings was converted into superphosphate (18-20% P_2O_5) and was given as four top dressings, two before anthesis and 2 after at equal intervals. The superphosphate was sprinkled over the surface of the compost and watered in. The top dressings of nitrogen and potassium were applied as fifteen liquid feeds starting one week after seed emergence and thereafter every five days. The changes in the mode and number of applications of the base and top dressings in comparison with those in Experiment No.1 were made in order to obtain a greater uniformity of fertilizer application through the plant growth, and better distribution in the compost.

Compost Preparation

Twenty-seven different composts were prepared, corresponding to the twenty-seven treatments, in the same way as for Experiment No.1.

Stock Solution Preparation

The liquid feeds were prepared by taking the required amounts from the prepared stock solutions and diluting with plain water, at a dilution rate of 1:100 and then applying to each appropriate pot. Nine stock solutions were required, ie. all possible combinations between the three levels of nitrogen and three levels of potassium. The fertilizers used were, ammonium nitrate (NH_4NO_3) with 35% N and potassium sulphate (K_2SO_4) with 45% K (analytical grade). The concentration of the final liquid feeds in these nutrients was calculated from the amounts of nitrogen and potassium to be added (Table 7). The amounts of fertilizers required to 1ℓ stock solution was calculated using the formula:

TABLE 7 : NITROGEN AND POTASSIUM CONCENTRATIONS IN THE FINAL SOLUTION OF LIQUID FEEDINGS FOR EXPERIMENT No. 2

Nutrient Levels	Total amount of Nutrients for top dressings	Amount of Nutrients per top dressing	Concentrations in the final solution. ppm.
N_1	0.3 g N	0.02 g N	100
N_2	1.2 g N	0.08 g N	400
N_3	2.1 g N	0.14 g N	700
K_1	0.24 g K_2O or 0.20 g K	0.013 g K	65
K_2	0.96 g K_2O or 0.80 g K	0.053 g K	265
K_3	1.68 g K_2O or 1.40 g K	0.093 g K	465

$$\left.\begin{array}{l}\text{g. of fertilizer per} \\ \text{1}\ell\text{ of stock solution}\end{array}\right\} = \frac{\text{ppm of nutrient x dilution rate}}{1000} \times \frac{100}{\text{\% nutrient in fertilizer}}$$

(Bunt, 1976).

The dilution rate used was 1:100. The amounts of fertilizers for stock solutions and for each level are given in Table 8.

Cultural Details

The glasshouse temperature and ventilation were controlled as in Experiment No.1 and the daily maximum and minimum temperatures recorded during the experiment are given in Appendix 2. Three seeds were sown per pot and the resulting seedlings were thinned to one per pot as described for Experiment No.1.

The crop programme was as follows:

Seeds sown	10 April 1978
Emergence	20-24 April 1978
Thinning	28 April 1978
First Liquid Feeding (N, K)	28 April 1978 (The remainder every 5 days)
First Top Dressing (P)	9 May 1978
Second Top Dressing (P)	21 May 1978
Third Top Dressing (P)	2 June 1978
Fourth Top Dressing (P)	14 June 1978
Picking First Pods	10 July 1978
Picking Last Pods	2 August 1978

TABLE 8 : AMOUNT OF FERTILIZERS USED FOR THE STOCK SOLUTIONS FOR EXPERIMENT No. 2

Nutrient Levels	Amount of Fertilizer for 1ℓ stock solution. g.	Fertilizer
N_1	28.57	Ammonium nitrate
N_2	114.28	Ammonium nitrate
N_3	200.00	Ammonium nitrate
K_1	14.45	Potassium sulphate
K_2	58.89	Potassium sulphate
K_3	103.33	Potassium sulphate

During the plant growth the following observations were made for each plant:

1. The date of the first flower open.

2. The number of pods per harvest.

3. The number of seeds per pod.

4. The seed yield.

5. The total dry matter of stems (without leaves) after harvesting.

From these observations the following parameters were calculated:

1. Days from sowing to first flower open.

2. Total number of pods per plant.

3. Mean time to harvest (as in Experiment No.1).

4. Number of seeds per plant.

5. Number of seeds per pod.

6. Total seed yield per plant.

7. Total weight of empty pods.

8. Ratio of seed:empty pods.

9. Total dry weight of stems per plant.

Tests for Seed Quality

1st Test : Seed Size Determination

The seed size was determined as in Experiment No.1. The sample size was 25 seeds but there were ten replications.

2nd Test : Germination

The seed lots from the twenty-seven treatments produced were tested for germination with samples of 25 seeds each, randomly selected, and replicated four times. The design and the conditions were the same as in Experiment No.1.

3rd Test : Seedling Evaluation

As in Experiment No.1.

4th Test : Cold Test

This is a widely used vigour test, which imposes stress on germinating seeds by subjecting them to microorganisms and to a cool, moist soil environment (Heydecker, 1972; McDonald, 1975; Copeland, 1976). Seeds are sown in trays filled with moist field soil, and placed first in cold conditions for a period and then transferred to a temperature favourable for germination, in order to find out how many of them survived and which is their possible residual growth potential. It is a well-established test and is usually used for seeds of warm season crops.

The development of this test started with corn seeds (Rice, 1960) and later it's use extended to other crops like soybeans (Byrd and Delouche, 1971), cotton (Mahdi *et al*, 1971), onions (Clark and Kline, 1962), sorghum (Pinthus and Rosenblum, 1961) and canary grass (Mark and McKee, 1968). The cold test indicates how a seed lot may be expected to perform when sown under cool, moist early spring conditions.

French beans are a summer crop with seeds which are sensitive to cool and moist conditions (Hardwick and Innes, 1975). But the bean growers are trying to establish the crop in the field as early as possible in the spring to extend the cropping season, and supply the processing industry. For the reasons outlined above it was decided to use this test in evaluating the vigour of the seed lots produced in these experiments, although there are some arguments concerning repetition of the test reproducibility (Heydecker, 1972). But Heydecker also states in the same paper that the test can be useful for comparison of seed lots when sown side by side and ranked according to their relative performance.

There are no references to the use of the cold test for french beans. Therefore, in order to run this test the following had to be decided:

1. Sowing media (soil or mixture of soil and sand).
2. Moisture level in sowing media.
3. Temperature for the cold period.
4. Duration of the low temperature.

After studying the papers cited above concerning the use of the cold test with different species the following was decided:

1. Sowing media to be a mixture of soil and sand, in a 1:1 v/v ratio.

2. The moisture level in the soil and sand mixture to be adjusted to 60% saturation.

3. The temperature for the cold period to be 10-12°C.

4. The trays with the mixture and the seeds to be kept for seven days under the low temperatures.

The soil for the cold tests was taken from plots on the University Field Station on which French beans had been grown the two preceeding years. The soil was sieved through a 5 mm screen and mixed throroughly with fine sand in a 1:1 v/v ratio, the mixture was then stored in plastic bags until required. Four samples, each of 25 seeds, were taken randomly from each of the seed lots produced from the twenty-seven treatments. Plastic trays, size 15 cm x 21 cm x 5 cm, were half filled with the prepared mixture. One sample of 25 seeds, was sown per tray and covered with the same mixture to the top of the tray. After adding a calculated quantity of water to adjust the moisture content of the mixture to 60% saturation, the trays were tightly covered with plastic film to prevent evaporation and transferred to a cold room with 10-12°C temperature. After seven days they were moved to a glasshouse and maintained there until no more germination occured. The experimental design was a randomised block with factorial arrangement.

The percentage of normal emerged seedlings, and the percentage of mortality (non-germinating seeds) were determined for each tray.

5th Test : Electrical Conductivity

The determination of the amounts of inorganic salts released from seed when soaked, has been found to be significantly correlated with the number of viable wrinkle-seeded peas.(Matthews and Whitbread, 1968). A similar relationship, between seed vigour and seed exudation was found with peas and beans in other work described by Matthews and Bradnock (1968). The amounts of inorganic salts were determined by measuring the electrical conductivity of a solution after soaking seeds in de-ionised water. This electrical conductivity measurement has been further developed and is currently accepted in the U.K. as an official test for pea seed to be sown by commercial growers (McKay, 1970), it is referred to as the electrical conductivity test. In this test the higher the conductivity of material leached out of the seed, the higher is the electrical conductivity of the water in which the sample seeds were soaked. The relationship between the electrical conductivity of the leachate and seed vigour is inversely proportional.

The leakage of metabolites from seed tissues is related to biochemical changes (Heydecker, 1972). Heydecker (1972) and Woodstock (1973) in their review papers concluded that low vigour could be associated with a weakening of cell membranes and/or with a loss of essential cell constituents and that the consequent leakage of sugars and electrolytes from cells results in:

1. A deterioration of the metabolic and transport efficiency, and
2. The attraction micro-organisms when the seed is grown.

Although the electrical conductivity test does work for French beans (Matthews and Bradnock, 1968), it is not yet sufficiently well developed enough to be recommended commercially as an official test, as is the case with peas (Matthews, 1977). In conclusion, because the electrical conductivity test is measuring seed vigour from a different aspect than the other tests, and as it has been shown to work for French beans, it was decided to include it as an assessment in these experiments.

The procedure which has been standardised by PGRO (1978) for peas, was used but the seed sample number and volume of water was modified. Treatments which included the lowest level of phosphorus were excluded because of low seed yield. From the remaining eighteen seed lots, four samples each of twenty-five seeds were taken randomly and weighed to one decimal place. The samples were then transferred to glass containers to which 125 cc of de-ionised water was added. The containers were then covered to prevent evaporation and entry of foreign matter. A separate container of de-ionised water without seeds was prepared (blank sample). All containers were kept at 20^{o}C for 24 hours. After removing the seeds with a coarse sieve, a reading in micro-Seimens (μS) was taken of the blank container and of each of the solutions, using the electrical conductivity meter, model P310 with the PE10 platinum black dip-type cell. The weight of dry seed was divided into the conductivity results for each of the replicate seed samples. The numbers obtained represent vigour grades in μSg^{-1}.

Seed Nitrogen, Phosphorus and Potassium Determination

To explain possible differences in seed vigour due to the different mother plant treatments, and to attempt the correlation of results from this work with the results of other workers, the seed content of nitrogen, phosphorus and potassium were determined.

The determination was based on a Kjeldahl digest solution (O'Neill and Webb, 1970; Allen, 1974; Robinson, 1978). The procedure was as follows:

(1) Sample Preparation

Samples of 25 seeds were each randomly taken from each of the twenty-seven seed lots and were ground. Before the digestion, sub-samples were dried in an electric oven at 105°C for 1 h. After cooling 0.05 g of each of the dried samples of selenium-sulphuric acid mixture were added, the tubes placed in aluminium blocks and left for digestion over bunsen flames. When the samples became clear and after cooling, de-ionised water was added to make up to 20 ml. The resulting solution was filtered and used for the subsequent determinations.

(2) Nitrogen Determination

Nitrogen was determined colorimetrically by the indophenyl blue complex. The reagents used were alkaline phenol, and sodium hypochloride.

(3) Phosphorus Determination

Phosphorus was determined colorimetrically by the yellow phospho-vanadate complex. The reagent used was the vanadate-molybdate reagent.

(4) Potassium Determination

Potassium was determined by emission flame photometry using an EEL flame photometer.

(5) Standard Solutions

To make a range of standard solutions, used to standardise the meters and to prepare the necessary graphs before each determination, the following chemicals were dissolved in 50 ml sulphuric acid:

1.	ammonium sulphate	0.5895 g	(analar)
2.	sodium dihydrogen phosphate	0.1219 g	do.
3.	potassium chloride	0.1192 g	do.

This solution was made up to 500 ml with de-ionised water. This gave a solution containing 250 ppm N, 50 ppm P and 125 ppm K. To make the range of standards the following amounts were taken and made up to 50 ml with 10% v/v sulphuric acid:

Vol. of Stock	Standard (μg/ml)
10 ml	50 N - 10 P - 25 K
20 ml	100 N - 20 P - 50 K
30 ml	150 N - 30 P - 75 K
40 ml	200 N - 40 P - 100 K

(6) Presentation of Results

Element concentrations are expressed on a percentage dry weight basis. The concentration of element in the original dry matter is given by:

$$C = \frac{\mu g/ml \text{ (from graph)}}{\text{weight of sample in } \mu g} \times \text{dilution factor} \times 100.$$

Experiment No. 3

With this experiment the effects of different levels of nitrogen and molybdenum on seed yield and quality of French beans were examined. The experiment was conducted during the Summer and Autumn of 1978 in an East-West orientated glasshouse. The cultivar, the peat:sand ratio and the size of plastic pots were the same as in the previous experiments.

The nutrient levels were selected, taking into account the results from Experiment No.1, and were as follows:

N_1 : 0.45 g N/pot	M_1 : 0 mg Mo/pot
N_2 : 0.90 g N/pot	M_2 : 5 mg Mo/pot
N_3 : 1.80 g N/pot	M_3 : 10 mg Mo/pot
	Mn : 20 mg Mo/pot

The treatments in the experiment were all possible combinations of the selected nutrient levels (e.g. 3N x 4 Mo = 12 treatments) and were arranged in a factorial randomised block design of six replications. These twelve treatments were applied as twenty liquid feeds every three days starting immediately after seed emergence. The other two main nutrients, phosphorus and potassium were applied as a base dressing at a uniform rate, the same as in the GCRI compost. The micronutrients B, Cu, Fe, Mn, Zn were also given at a uniform rate as in Frit No.253A. The applications of all these micronutrients were made in twenty liquid feeds together with the treatments.

Compost Preparation

Sufficient uniform compost was prepared for 72 six litre pots. Three parts peat and one part fine sand were mixed thoroughly. To this mixture were added:

2.25 g/ℓ dolomite limestone

2.25 g/ℓ ground limestone

1.53 g/ℓ superphosphate (18-20% P_2O_5) and

0.73 g/ℓ potassium sulphate (48% K_2O).

Preparation of Stock Solutions for Treatments

The total amount per liquid feed of nitrogen and molybdenum are given in Table 9. The liquid feeds were applied by taking the required amounts from the prepared stock solutions, diluting them in plain water at a rate of 1:200 and from this solution 200 cc were applied as appropriate to each pot. The fertilizers used were:

Ammonium nitrate	35% N	(analytical grade) and	
Ammonium molybdate	56% Mo,	do	
	7% N	do	

Using the same formula as in Experiment No.2 the amounts of fertilizers for 1ℓ stock were calculated (Table 10).

TABLE 9 : AMOUNT OF NUTRIENTS PER NUTRIENT LEVEL AND PER LIQUID FEEDING IN EXPERIMENT No. 3

Nutrient Levels	Amount per pot	Amount per feed. mg.	Concentration at the final solution. ppm.
N_1	0.45 g N	22.5	112.5
N_2	0.90 g N	45.0	225.0
N_3	1.80 g N	90.0	450.0
M_1	0 mg Mo	0.00	0.00
M_2	5 mg Mo	0.25	1.25
M_3	10 mg Mo	0.50	2.50
M_4	20 mg Mo	1.00	5.00

TABLE 10 : AMOUNT OF FERTILIZERS USED FOR THE STOCK SOLUTIONS IN EXPERIMENT No. 3

Nutrient Levels	Amount of Fertilizer for 1ℓ stock solution. g.	Fertilizer
N_1	64.28	Ammonium nitrate
N_2	128.27	Ammonium nitrate
N_3	257.14	Ammonium nitrate
M_1	0.00	Ammonium molybdate
M_2	0.45	Ammonium molybdate
M_3	0.90	Ammonium molybdate
M_4	1.84	Ammonium molybdate

Preparation of Stock Solutions for Micronutrients

If 0.4 g/ℓ, i.e. 2.4 g/pot of fritted trace element No.253A was added to the compost, the following amounts of micronutrients need to be added per pot:

B	=	2.40 x 0.02	=	0.048 g	or	48	mg
Cu	=	2.40 x 0.02	=	0.048 g	or	48	mg
Fe	=	2.40 x 0.1225	=	0.294 g	or	294	mg
Mn	=	2.40 x 0.049	=	0.118 g	or	118	mg
Zn	=	2.40 x 0.04	=	0.096 g	or	96	mg

In this experiment these amounts of micronutrients were applied not as Frit No.253A but as twenty liquid feeds, together with the treatment nutrients. The amounts per liquid feed and the concentration of the final solution are as follows:

	Amount per ℓ.f (mg)	Concentration (ppm)
B	2.4	12.0
Cu	2.4	12.0
Fe	14.7	73.5
Mn	5.9	29.5
Zn	4.8	24.0

The fertilizers used were:

Boric acid	17.45%	B	Analytical grade
Cupric sulphate	25.45%	Cu	do.
Ferric citrate	16.67%	Fe	do.
Manganese sulphate	24.63%	Mn	do.
Zinc sulphate	22.74%	Zn	do.

Using the formula as in Experiment No.2 the amounts of fertilizers for 1ℓ stock solution were calculated in gr.

Boric acid	13.75
Cupric sulphate	9.43
Ferric citrate	88.18
Manganese sulphate	23.95
Zinc sulphate	21.11

The required amounts were taken from the prepared stock solutions and diluted with plain water at a rate of 1:200 and then applied as the treatment liquid feeds.

Cultural Details

The glasshouse temperature and ventilation were controlled as in previous experiments. The maximum and minimum temperatures recorded each day during the experiment are given in Appendix 3. Three seeds were sown per pot and the resulting seedlings were thinned to one per pot as described for the previous experiment.

The crop programme was as follows:

Seeds sown	6 August 1978	First liquid feeding (the rest every three days)	17 August 1978
Emergence	14-17 August 1978	Picking first pods	23 October 1978
Thinning	25 August 1978	Picking last pods	10 November 1978

All the other cultural details were similar to those in the previous experiments. During the plant growth observations were made and the parameters were calculated as in Experiment No.2.

To test the seed quality all the tests and chemical analysis were made as in Experiment No.2. The treatments were replicated four times in all the tests with the exception of the 100-seed weight determination where the replications were ten.

Experiment No. 4

A field experiment was designed to evaluate the effects of nitrogen, phosphorus and potassium. It was appreciated that the South-West of England is not a very suitable seed production area but as the marketable crop is grown successfully it was thought that an evaluation of the effects of nutrient regimes on seed production in the field could be successful.

The experiment was conducted during the Spring and Summer of 1978 in the University Field Station at Claverton Down. The same cultivar 'Cascade' was used as in all the previous experiments. In order to decide on the levels of nitrogen, phosphorus and potassium the following were taken into consideration:

(1) A soil analysis report by ADAS (1976) for the field.

(2) The fertilizer recommendations by the Ministry of Agriculture(1973a).

(3) The fertilizer recommendations by PGRO (1975 a).

The soil analysis gave the following results:

Soil texture	:	Silty loam	
Soil pH	:	7.0	
Phosphorus	:	30 mg/ℓ	Index 3
Potassium	:	150 mg/ℓ	Index 2
Magnesium	:	172 mg/ℓ	Index 3

According to this analysis and the Ministry of Agriculture recommendations the following amounts of nitrogen, phosphorus and potassium were required for a normal fresh crop:

Nitrogen	:	125	Kg N/ha
Phosphorus		125	Kg P_2O_5/ha
Potassium		112.5	Kg K_2O/ha

According to the PGRO Beans Handbook the following amounts of nutrients should be added to a silty soil for a normal fresh crop:

Nitrogen : 144 Kg N/ha
Phosphorus : 94 Kg P_2O_5/ha
Potassium : 50 Kg K_2O/ha

The above ADAS and PGRO recommendations were taken as a basis for deciding on the quantities to apply in the experiment. The lower level was therefore based on nutrient requirements for a fresh crop and the higher level was 50% above this:

N_1 :	150 Kg N/ha	N_2 :	225 Kg N/ha
P_1 :	120 Kg P_2O_5/ha	P_2 :	180 Kg P_2O_5/ha
K_1 :	60 Kg K_2O/ha	K_2 :	90 Kg K_2O/ha

The treatments in the experiment were all possible combinations of the selected nutrient levels (e.g. 2N x 2P x 2K = 8 treatments). These were arranged in a factorial randomised block design of four replications.

The nutrients in all the treatments were applied as base dressings before sowing, except for 25% from each of the nitrogen levels, which was given as a top dressing before anthesis. The fertilizers used for the base dressing were ammonium sulphate (21% N), triple superphosphate (47% P_2O_5) and potassium sulphate (48% K_2O), but for the top dressing ammonium nitrate (35% N) was used. The amounts of nutrients and fertilizers per treatment and dressing are given in more detail in Table 11.

The area used for the experiment was 225 m^2, including the experimental blocks and paths between blocks. Each of the four blocks was 3.0 m x 12.8 m and consisted of eight plots, one for each treatment, size 3 m x 1.6 m. The area had been rotovated early in the Spring.

TABLE 11 : AMOUNT OF NUTRIENTS AND FERTILIZERS USED PER TREATMENT AND DRESSING IN EXPERIMENT No. 4

Treatments			Amount of Nutrient			Kg/ha.	Amount of Fertilizer			Kg/ha.
			Base Dressing			Top Dressing	Base Dressing			Top Dressing
			N	P_2O_5	K_2O	N	Am.sul.	Sup.ph.	Pot.sul.	Am.nit.
N_1	P_1	K_1	120	120	60	30	571.5	255.3	125.0	85.7
		K_2	120	120	90	30			187.5	
	P_2	K_1	120	180	60	30		383.0	125.0	
		K_2	120	180	90	30			187.5	
N_1	P_1	K_1	180	120	60	45	857.1	255.3	125.0	128.6
		K_2	180	120	90	45			187.5	
	P_2	K_1	180	180	60	45		383.0	125.0	
		K_2	180	180	90	45			187.5	

Two weeks before sowing the herbicide 'Trifluralin' was applied to the area. The plots were then marked out and the appropriate amounts of fertilizers for the base dressings were applied to the different plots, and rotovated to improve fertilizer incorporation and distribution. Each plot was rotovated separately.

Seed Sown

The seeds were sown in rows 40 cm apart. Each plot, therefore, contained four rows of plants, from which only the middle two were harvested. On each row 50 seeds were sown at a depth of 3-4 cm.

Cultural Details

The crop programme was as follows:

Seed sown	24 May 1978
Emergence (start)	4 June 1978
Top Dressing	17 July 1978
Harvest	12 October 1978

After emergence the plants were irrigated by oscillating spray lines when required.

During the plant growth dimethoate was used to control black flies *(Aphis fabae)* and benomyl to control botrytis *(Botrytis cinerea)* when necessary.

The plants of the two rows, in the middle of each plot, were harvested at one time by pulling them from the soil, and then they were spread in a glasshouse to dry. One month later the pods were picked at random from 50 plants per plot, and they were left another two weeks for further drying. Lastly the seeds were extracted from the pods and were stored in paper bags under laboratory conditions.

Climatic Conditions

The daily maximum and minimum air temperatures and the daily precipitation are given in Appendix 4.

Tests for Seed Quality

All the tests and seed chemical analysis described earlier were used to assess seed quality. Each test was replicated eight times for the germination test, seedling evaluation test, cold test and seed size determination, and four times for the electrical conductivity test.

The procedures and the sample size were as in the previous experiments.

2. PROGENY PERFORMANCE

Experiment No. 5

With this experiment the effects of mother plant nutrition on progeny performance of French beans were examined.

Seeds from seed lots, produced from the mother plant treatments of the first nutritional experiment were sown in compost and the resulting plants were grown under two different nutrient regimes, one low in the main nutrients and one high.

The following 14 seed lots were examined (the numbers refer to the treatment numbers in Experiment No.1):

No. 1	$N_1\ P_1\ K_1\ M_1$	No. 36	$N_2\ P_3\ K_3\ M_2$
3	$N_1\ P_1\ K_2\ M_1$	37	$N_3\ P_1\ K_1\ M_1$
5	$N_1\ P_1\ K_3\ M_1$	42	$N_3\ P_1\ K_3\ M_2$
7	$N_1\ P_2\ K_1\ M_1$	48	$N_3\ P_2\ K_3\ M_2$
13	$N_1\ P_3\ K_1\ M_1$	50	$N_3\ P_3\ K_1\ M_2$
18	$N_1\ P_3\ K_3\ M_2$	52	$N_3\ P_3\ K_2\ M_2$
19	$N_2\ P_1\ K_1\ M_1$	54	$N_3\ P_3\ K_3\ M_2$

The two selected nutrient regimes were:

(1) Low: N = 0.6 g/pot, P_2O_5 = 0.15 g/pot, K_2O = 0.6 g/pot
(2) High: N = 1.8 g/pot, P_2O_5 = 0.75 g/pot, K_2O = 1.5 g/pot

Therefore the treatments in the experiment were all possible combinations between the 14 seed lots and the two nutrient regimes (e.g. 14 x 2 = 28 treatments). These were arranged in a factorial randomised block design of four replications.

The experiment was conducted during the Spring and Summer of 1978 in an East-West orientated heated glasshouse.

Compost Preparation

Sufficient uniform compost was prepared for 112 (28 x 4) six litre pots by thoroughly mixing two parts peat and one part fine sand. To this mixture the following were added:

2.25 g/ℓ dolomite limestone
2.25 g/ℓ ground limestone
0.40 g/ℓ Frit 253A

Preparation of Stock Solutions for Treatments

The two different regimes (Low and High) were applied as 15 liquid feeds throughout the plant growth at five day intervals, starting five days after the seed emergence. The required amounts were taken from the prepared stock solutions, they were diluted with plain water at a rate of 1:200 and from this solution 200 cc was applied as appropriate, to each pot.

The fertilizers used were:

(1) monoammonium phosphate	N = 11.93%	P = 26.39%
(2) potassium nitrate	N = 13.72%	K = 38.28%
(3) ammonium nitrate	N = 34.3%	

Table 12 gives the total amounts of the main nutrients given under the two nutrient regimes per plant, the amounts per feed and the concentration in the final solution for the liquid feed. Using the same formulae as in Experiment No.2 the amounts of fertilizers for 1ℓ stock solution were calculated (Table 13).

TABLE 12 : AMOUNTS OF MAIN NUTRIENTS PER PLANT AND PER FEED APPLICATION IN THE TWO NUTRIENT REGIMES FOR EXPERIMENT No. 5

Nutrient Regime	Amount per plant. g.	Amount per feed. mg.	Concentration at the final solution. ppm.
Low: N	0.600	40.0	200.0
P	0.065	4.3	21.5
K	0.498	33.2	166.0
High: N	1.800	120.0	600.0
P	0.327	21.8	109.0
K	1.245	83.0	415.0

TABLE 13 : AMOUNTS OF FERTILIZERS FOR 1 LITRE STOCK SOLUTION PER NUTRIENT REGIME, IN EXPERIMENT No. 5.

Nutrient Regime	Fertilizer	Amount of Fertilizer. g.
Low	Monoammonium phosphate	16.52
	Potassium nitrate	86.73
	Ammonium nitrate	76.18
High	Monoammonium phosphate	82.61
	Potassium nitrate	216.82
	Ammonium nitrate	234.39

Cultural Details

The glasshouse temperature and ventilation were controlled as in previous experiments. The daily maximum and minimum temperatures during the experiment are given in Appendix 3.

Three seeds were sown per pot and the resulting seedlings were thinned to one per pot as described in the previous experiments.

The crop programme was:

Seeds sown	20 April 1978
Emergence	27-29 April 1978
Thinning	5 May 1978
First liquid feed	5 May 1978 (the remainder every 5 days)
Picking first pods	11 July 1978
Picking last pods	31 July 1978

During the seedling growth and before thinning, the seedling height was measured from the compost level up to growing point. From this observation the mean seedling height one week after the emergence was calculated. All the other observations were taken and the parameters were calculated as in previous experiments.

To test the seed quality, only the seedling evaluation and seed size determination were made (described in previous experiments) because of low yield in some of the treatments.

3. HARVEST STAGES AND POD POSITION ON THE MOTHER PLANT

Experiment No. 6

In this experiment the effects of time of harvest and pod position on seed yield and quality were studied. The experiment was conducted during the Summer and Autumn of 1977 following Experiment No.1 in the same glasshouse.

Five seeds of the cultivar 'Cascade' were sown in each 6 litre pot, containing Levington potting compost. The resulting seedlings were thinned to one per pot as described for the previous experiments. The experimental design was a randomised block with four replicates. Each block consisted of six plots and each plot of four pots with one plant each.

There were six harvest stages and at each stage the plants were taken from four plots, one from each block selected at random. The pods were removed and separated into two groups on the basis of their position on the plant. Each of the two groups were termed 'main' (M) or 'secondary' (S). The 'main' group included pods from the main axis and the 'secondary' group included pods from the secondary branches (Figure 1). The pods were dried under laboratory conditions until they reached a constant weight. The seeds were then removed from the pods and left for a further two weeks before being placed in paper bags and stored at room temperature.

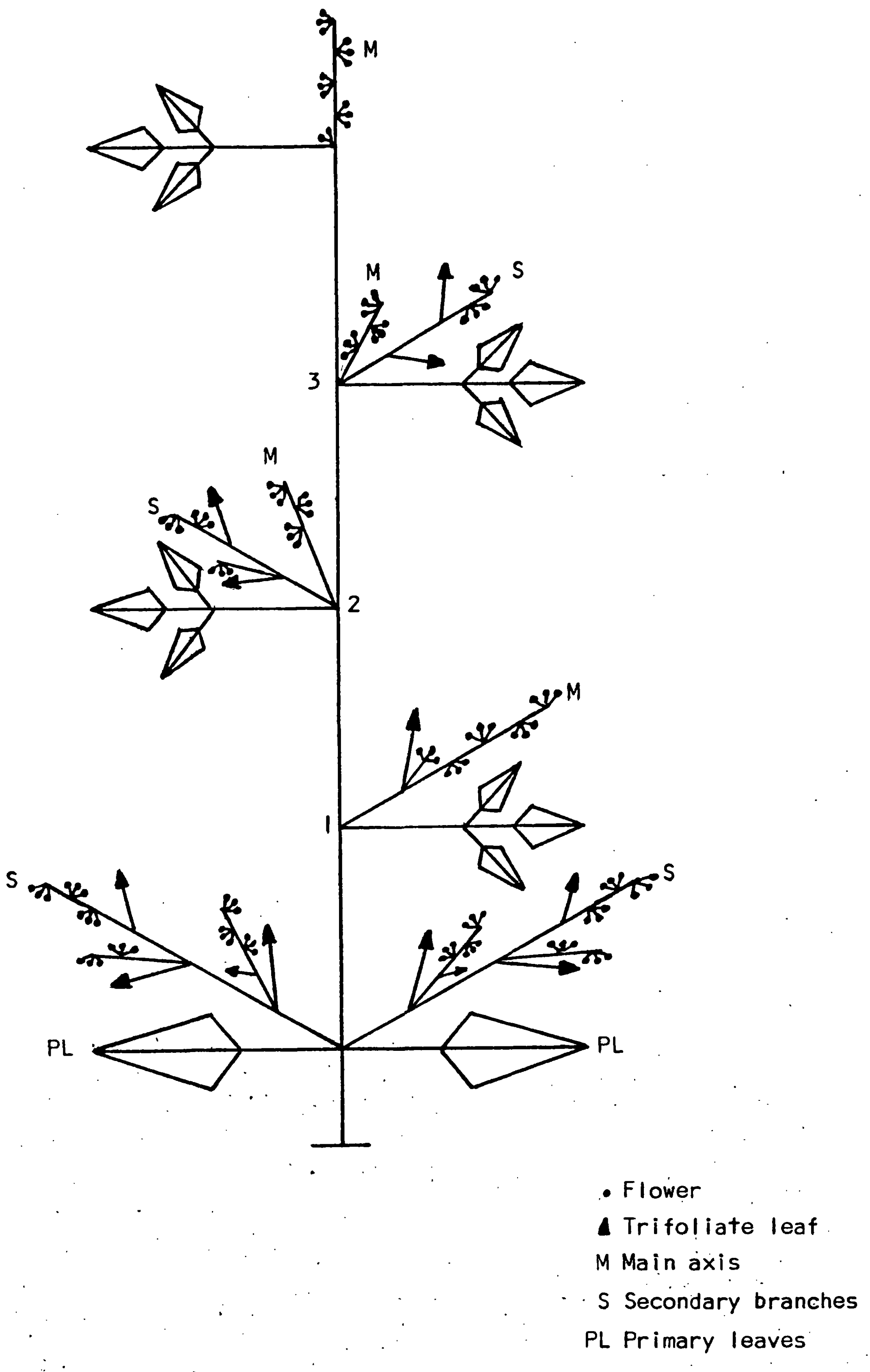

FIGURE I : Diagram of a bean plant showing the pattern of branch and flower disposition per node.

Cultural Details

The glasshouse temperature and ventilation were controlled as in previous experiments. The maximum and minimum temperatures recorded each day during the experiment are given in Appendix 1.

The crop programme was as follows:

Seeds sown	11 August 1977	3rd Harvest	14 November 1977
Emergence	17-19 August 1977	4th Harvest	20 November 1977
Thinning	27 August 1977	5th Harvest	26 November 1977
1st Harvest	2 November 1977	6th Harvest	2 December 1977
2nd Harvest	8 November 1977		

All the other cultural details were similar to those in the previous experiments. The first day of flowering was recorded for each individual plant. The following observations were made at each harvest day:

(1) The number and weight of pods at each position.
(2) The seed and pod moisture content per position.
(3) The dry matter of stems (excluding leaves).

After drying the following observations were made for each harvest.

(1) The number of seeds per position.
(2) The number of seeds per pod and position.
(3) The seed yield.

Tests For Seed Quality

To estimate the seed quality the following evaluations were made:

(1) Seed size determination.
(2) Germination test.
(3) Seedling evaluation test.

The procedures and the sample size for these tests were the same as in the previous experiments.

Experiment No. 7

This experiment was similar to Experiment No.6 and was conducted in the Summer and Autumn of 1978 following Experiment No.2 in the same glasshouse. The cultivar, compost and pot size were the same as in Experiment No.6. The experimental design was a randomised block design with four replicates. Each block consisted of eight plots, and each plot of four pots with one plant each.

There were eight harvest stages and the harvesting procedure for each of them was the same as in Experiment No.6.

Cultural Details

The glasshouse temperature and ventilation were controlled as in previous experiments. The maximum and minimum temperatures recorded each day during the experiment are given in Appendix 2.

The crop programme was as follows:

Seeds sown	11 August 1978
Emergence	17-20 August 1978
Thinning	30 August 1978
1st Harvest	25 October 1978
2nd Harvest	31 October 1978
3rd Harvest	6 November 1978
4th Harvest	12 November 1978
5th Harvest	18 November 1978
6th Harvest	24 November 1978
7th Harvest	30 November 1978
8th Harvest	6 December 1978

All the other cultural details were the same as in previous experiments.

During the plant growth, 40 plants (10 from each replicate) were selected randomly and the number of open flowers was recorded per plant and per branch every two days. From these observations the total number of flowers per branch and per plant, and the mean time of flowering per branch were calculated. The observations taken at each harvesting time and after drying were the same as in Experiment No.6.

Tests for Seed Quality

The following tests were used with the same procedures as in previous experiments:

(1) Seed size determination.

(2) Germination test.

(3) Seedling evaluation test.

(4) Cold test.

(5) Electrconductivity test.

D. RESULTS

1. MOTHER PLANT NUTRITION EXPERIMENTS

Experiment No. I

Plant Growth

The length of the main axis, secondary and tertiary branches were measured after harvesting in order to examine the effects of the nutrient levels on plant growth. It was found from the analysis of variance that only the phosphorus levels significantly affected the length of the main axis, secondary and tertiary branches, and the total plant length at 1% level of significance. In addition none of the interactions between N, P, K and Mo significantly affected the characters contributing to plant height. The mean length of the main axis, secondary and tertiary branches and the mean total plant length per nutrient level (main effects) are given in Table 14.

It was therefore found that the 3rd level of phosphorus increased the plant growth, which was followed by the 2nd and 1st levels respectively ($P_3 > P_2 > P_1$). Although the effects of the other nutrients did not significantly affect the plant growth, it can be observed from Table 14 that the trend of total plant length increased with the 2nd levels of N and K and decreased with the 3rd levels of N and K and 2nd level of Mo.

TABLE 14 : The influence of N, P, K and Mo (main effects) on mean length of main axis, secondary branches, tertiary branches and total plant length.

Nutrient Levels	Main Axis (cm)	Secondary Branches (cm)	Tertiary Branches (cm)	Total plant Length (cm)
N_1	38.70 a	178.80 a	44.20 a	261.70 a
N_2	37.98 a	185.20 a	48.70 a	271.90 a
N_3	37.71 a	180.50 a	47.30 a	266.00 a
5% LSD	2.015	14.484	7.468	20.96
P_1	28.62 c	58.90 c	4.40 c	91.60 c
P_2	41.06 b	210.20 b	51.60 b	302.80 b
P_3	44.72 a	275.40 a	84.40 a	404.90 a
5% LSD	2.015	14.484	7.468	20.96
K_1	38.04 a	177.50 a	42.50 a	258.10 a
K_2	37.60 a	183.50 a	50.50 a	272.00 a
K_3	38.76 a	183.50 a	47.30 a	269.60 a
5% LSD	2.015	14.484	7.468	20.96
M_1	38.41 a	181.90 a	47.80	268.10 a
M_2	37.85 a	181.10 a	45.50	264.90 a
5% LSD	1.644	11.819	6.096	17.11

Note 1: Each datum for N,P,K is the mean of 72 plants and for Mo is the mean of 108 plants.

Note 2: Data followed by different letters (a, b, c) within a subcolumn are significantly different.

Flower Number

There is evidence that the number of flowers per plant is affected by the phosphorus levels, but not by the nitrogen, potassium and molybdenum levels which were also examined. The phosphorus main effect is significant at 1% level. There are also no marked interactions between N, P, K and Mo. The mean number of flowers for each plant and per nutrient level are given in Table 15.

TABLE 15 : The influence of N, P, K and Mo (Main effects) on mean number of flowers per plant

Nutr. Level	Means of 36 Plants			Means of 54 Plants
	N	P	K	Mo
1st	57.8 a	26.9 c	57.7 a	61.3 a
2nd	63.6 a	67.9 b	59.3 a	60.7 a
3rd	61.5 a	88.1 a	66.0 a	-
5% LSD	9.152	9.152	9.152	7.466

Data followed by different letters (a, b, c) within a column are significantly different.

It is therefore observed that the 3rd level of phosphorus increased flower formation followed respectively by the 2nd and 1st levels ($P_3 > P_2 > P_1$).

Number of Pods per Plant

From the analysis of variance it was found that all the main nutrients, N, P and K significantly affected the number of pods per plant, N and P at 1% level and K at 5% level of significance.

From the nutrient interactions the NP Mo was found to be just significant at 5% level and NP significant at 5% level. The mean number of pods per plant and per nutrient level are given in Table 16.

TABLE 16 : The influence of N, P, K and Mo (Main effects) on Mean Number of Pods per Plant

Nutr. Level	Means of 72 Plants			Means of 108 Plants
	N	P	K	Mo
1st	14.29 b	4.32 c	14.46 b	15.37 a
2nd	15.57 a	17.79 b	15.72 a	15.06 a
3rd	15.79 a	23.54 a	15.47 a	-
5% LSD	0.975	0.975	0.975	0.796

Data followed by different letters (a, b, c) within a column are significantly different.

When comparing the means it can be observed in the case of nitrogen that the second and third levels gave the highest number of pods per plant and the first level the lowest ($\underline{N_3, N_2}$, N_1). In the case of phosphorus the 3rd level gave the highest number of pods per plant followed by the 2nd and 1st levels ($P_3 > P_2 > P_1$), and in the case of potassium the 2nd and 3rd levels gave the highest number of pods per plant and the 1st level the lowest ($\underline{K_2, K_3}$, K_1).

The mean number of pods per plant due to the interaction between nitrogen and phosphorus levels are given in Table 17.

TABLE 17 : The inflence of N and P interaction on Mean Number of Pods Per Plant

Nutrient	Means of 24 Plants		
	P_1	P_2	P_3
N_1	4.46 e	16.42 d	22.00 b
N_2	4.38 e	19.00 c	23.33 b
N_3	4.13 e	17.96 cd	25.29 a

5% LSD = 1.689

Data followed by different letters (a, b, c, d, e) are significantly different.

It can be concluded that the dominant factor is phosphorus because the values due to the 3rd level (disregarding the nitrogen levels) are well above all the others and the values due to the 2nd level are well above those due to the 1st level. Within the 1st level of P there are no significant differences resulting from the nitrogen levels, within the 2nd level of P both the 2nd and 3rd levels of nitrogen gave the best results. Within the 3rd level of P the best results were obtained from the 3rd level of nitrogen.

Percentage of Pod Setting

The percentage of pods setting per plant were calculated, and after transformation into angles were statistically analysed. From the analysis of variance it was found that only the phosphorus levels significantly affected these percentages at 1% level of significance. The percentage of setting was also unaffected by the interactions between N, P, K and Mo.

The means of pod setting per plant and per nutrient level are given in Table 18 in angles and percentages.

TABLE 18 : The influence of N, P, K and Mo (Main effects) on the Percentage of Pod Setting

Nutr. Level	Means of 36 Plants						Means of 54 Plants	
	N		P		K		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	28.67 a	23.00	23.90 b	16.40	28.77 a	23.20	28.65 a	23.00
2nd	28.71 a	23.10	31.03 a	26.60	29.74 a	24.60	29.02 a	23.50
3rd	29.12 a	23.70	31.57 a	27.40	27.99 a	22.00	-	-

5% LSD (for the angles): N 2.294; P 2.294; K 2.294; Mo 1.872

Data followed by different letters (a, b) within a column are significantly different.

It is therefore observed that both the 3rd and 2nd levels of phosphorus gave a better pod setting than the first level (<u>P_3, P_2</u>, P_1).

Number of Seeds Per Plant

There is evidence that the number of seeds per plant is affected by the phosphorus level, but not by the levels of the other nutrients N, K and Mo. From the interactions only the N Mo interaction showed a significant effect. The main effect of phosphorus is highly significant at 1% level and the interaction N Mo just significant at 5% level.

The mean number of seeds per plant due to the main effects of N, P, K, Mo and due to the interaction N Mo are given in Tables 19 and 20.

TABLE 19 : The Influence of N, P, K and Mo (Main effects) on Mean Number of seeds per plant

Nutr. Level	Means of 72 Plants			Means of 108 Plants
	N	P	K	Mo
1st	61.21 a	16.61 c	60.76 a	63.30 a
2nd	61.71 a	72.99 b	63.49 a	61.48 a
3rd	64.25 a	97.57 a	62.92 a	-
5% LSD	4.70	4.70	4.70	3.84

Data followed by different letters (a, b, c) within a column are significantly different.

TABLE 20 : The Influence of N Mo Interaction on Mean Number of Seeds Per Plant

Nutrient	Means of 36 Plants	
	M_1	M_2
N_1	65.83 a	56.58 b
N_2	61.17 ab	62.25 ab
N_3	62.89 ab	65.61 a

5% LSD = 6.64

Data followed by different letters (a, b) are significantly different.

From these results it can be concluded that the 3rd level of phosphorus gave the greater number of seeds per plant followed by the 2nd and 1st levels ($P_3 > P_2 > P_1$) and that the combinations N_1 M_1, N_3 M_2 gave better results than the combination N_1 M_2.

Number of Seeds Per Pod

The number of seeds per pod was calculated from the total number of seeds and number of pods per plant.

It was found from the analysis of variance that only the phosphorus levels affected the number of seeds per pod significantly at 5% level.

The mean number of seeds per pod and per nutrient level are given in Table 21.

TABLE 21 : The Influence of N, P, K and Mo (Main effects) on Number of Seeds Per Pod

Nutr. Level	Means of 72 Plants			Means of 108 Plants
	N	P	K	Mo
1st	4.195 a	3.879 b	4.167 a	4.126 a
2nd	4.000 a	4.125 a	3.957 a	4.000 a
3rd	3.995 a	4.186 a	4.066 a	-
5% LSD	0.233	0.233	0.233	0.190

Data followed by different letters (a, b) within a column are significantly different.

It is therefore evident that both the 3rd and 2nd levels of phosphorus gave better results than the 1st level, ($\underline{P_3, P_2}$, P_1). In practice these small differences (0.307 and 0.246), although significant, are not important as they are less than 1, which is the smallest difference in seeds per pod.

Seed Yield

From the analysis of variance it was found that only phosphorus levels significantly affected at the 1% level, and from the interactions between the different nutrient levels only the interaction N Mo affected the seed yield per plant significantly at 5% level.

The mean seed yield per plant and per nutrient level is given in Table 22.

TABLE 22 : The Influence of N, P, K and Mo (Main effects) on Seed Yield Per Plant

Nutr. Level	Means of 72 Plants (g)			Means of 108 Plants (g)
	N	P	K	Mo
1st	28.62 a	7.66 c	28.37 a	29.86 a
2nd	28.91 a	34.07 b	29.97 b	28.60 a
3rd	30.15 a	45.97 a	29.36 a	-
5% LSD	1.69	1.69	1.69	1.38

Data followed by different letters (a, b, c) within a column are significantly different.

It is therefore seen that the 3rd level of phosphorus significantly increased the seed yield per plant followed respectively by the 2nd and 1st levels, ($P_3 > P_2 > P_1$).

Although other nutrients did not change the seed yield significantly, a slight increase can be observed with the increased nitrogen and potassium and a slight decrease with the second level of molybdenum.

The mean seed yields for each combination of nitrogen and molybdenum levels are given in Table 23.

TABLE 23 : The Influence of N Mo Interaction on Seed Yield Per Plant

Nutrient	Means of 36 Plants (g)	
	M_1	M_2
N_1	30.51 a	26.74 b
N_2	29.01 ab	28.81 ab
N_3	30.07 a	30.24 a

5% LSD = 2.40

Data followed by different letters (a, b) are significantly different.

On examining this interaction it can be seen that within the first level of molybdenum there is no significant difference due to nitrogen levels but within the second level of molybdenum the lowest level of nitrogen gave a smaller seed yield than the 2nd and 3rd levels.

Seed to Empty Pod Ratio (S:EP)

Dividing the seed weight per plant by the empty pod weight the S:EP ratio has been calculated. The bigger this ratio the bigger the seed proportion from the total dry pod yield.

From the analysis of variance it has been found that this ratio was significantly affected by the phosphorus and potassium levels at 1% level of significance. From the interactions, those which significantly affected the S:EP ratio were the NK interaction, at 5% level, and the PK, PM interactions at 1% level.

The mean values of S:EP ratio per nutrient level are given in Table 24.

TABLE 24 : The Influence of N, P, K and Mo (Main effects) on Mean S:EP Ratio

Nutr. Level	Means of 72 Plants			Means of 108 Plants
	N	P	K	Mo
1st	2.484 a	2.612 a	2.615 a	2.444 a
2nd	2.354 a	2.157 b	2.378 b	2.420 a
3rd	2.457 a	2.527 a	2.303 b	-
5% LSD	0.110	0.110	0.110	0.090

Data followed by different letters (a, b) within the same column are significantly different.

It is therefore observed that the 1st and 3rd levels of phosphorus both gave a better ratio than the 2nd level ($\underline{P_1, P_3}$, P_2). The 1st level of potassium also gave a better ratio than both the 2nd and 3rd levels, (K_1, $\underline{K_2, K_3}$).

The values of S:EP ratio due to the P Mo interaction are given in Table 25.

TABLE 25 : The Influence of P Mo Interaction on Mean S:EP Ratio

Nutrient	Means of 36 Plants	
	M_1	M_2
P_1	2.670 a	2.553 ab
P_2	2.226 c	2.089 c
P_3	2.437 b	2.617 a

5% LSD = 0.155

Data followed by different letters (a, b, c) are significantly different.

It can be observed that the combinations P_1 M_1 and P_3 M_2 gave the best ratio followed by the P_1 M_2 and P_3 M_1 combinations. The values due to P_2 M_1 and P_2 M_2 are well below all the others.

The S:EP ratios due to the PK interaction are given in Table 26.

TABLE 26 : The Influence of PK Interaction on Mean S:EP Ratio

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
P_1	2.667 b	2.594 bc	2.575 bc
P_2	2.278 de	2.134 ef	2.060 f
P_3	2.899 a	2.406 cd	2.276 de

5% LSD = 0.190

Data followed by different letters (a, b, c, d, e, f) are significantly different.

The best S:EP ratio was achieved by the P_3 K_1 combination followed by the combinations P_1 K_1, P_1 K_2 , P_1 K_3.

The S:EP ratios due to the N K interaction are given in Table 27.

TABLE 27 : The Influence of NK Interaction on Mean S:EP Ratio

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
N_1	2.547 b	2.473 bc	2.432 bcd
N_2	2.520 b	2.999 cde	2.244 de
N_3	2.777 a	2.361 bcde	2.234 e

5% LSD = 0.190

Data followed by different letters (a, b, c, d, e) are significantly different.

The best S:EP ratio was achieved by the N_3 K_1 combination which is followed by the N_1 K_1, N_2 K_1 and then by the N_1 K_2 and N_1 K_3.

Seed Size Determination

(a) Weight of Individual Seeds

The mean seed weight per treatment has been calculated by dividing the total seed weight per plant by the total number of seeds per plant.

From the analysis of variance it has been found that the mean seed weight was not affected by the nutrients examined (N, P, K, Mo), but it was significantly affected by the N P K interaction at 5% level of significance.

The mean seed weights due to the N, P, K and Mo main effects and due to the N P K interaction are shown in Tables 28 and 29.

TABLE 28 : The Influence of N, P, K and Mo (Main effects) on Mean Seed Weight

Nutr. Level	Means of 72 Plants (g)			Means of 108 Plants (g)
	N	P	K	Mo
1st	0.468a	0.472 a	0.472 a	0.477 a
2nd	0.473 a	0.474 a	0.475 a	0.470 a
3rd	0.480 a	0.476 a	0.474 a	-
5% LSD	0.017	0.017	0.017	0.014

Data followed by different letters (a, b) within a column are significantly different.

Although the results are not significant it can be observed from this table that, in the case of nitrogen the trend of seed weight increased with the nitrogen.

TABLE 29 : The Influence of N P K Interaction on Mean Seed Weight

Nutrient	Means of 8 Plants (g)		
	K_1	K_2	K_3
N_1 P_1	0.480 abcdef	0.440 f	0.461 cdef
N_1 P_2	0.453 def	0.473 bcdef	0.473 bcdef
N_1 P_3	0.506 abc	0.465 cdef	0.462 cdef
N_2 P_1	0.447 ef	0.500 abcd	0.475 bcdef
N_2 P_2	0.463 cdef	0.474 bcdef	0.450 def
N_2 P_3	0.461 cdef	0.495 abcde	0.490 abcdef
N_3 P_1	0.463 cdef	0.458 cdef	0.518 ab
N_3 P_2	0.527 a	0.486 abcdef	0.462 cdef
N_3 P_3	0.448 ef	0.484 abcdef	0.477 abcdef

5% LSD = 0.051

Data followed by different letters (a, b, c, d, e, f) are significantly different.

It can be observed that the combinations N_3 P_2 K_1, N_3 P_1 K_3, N_1 P_3 K_1, N_2 P_1 K_2, N_2 P_3 K_2, produced seeds with higher seed weight than the average.

(b) 100 Seed Weight

The analysis of variance showed that the N, P, K and Mo main effects were insignificant but the N P K interaction significantly affected the 100 seed weight a 5% level of significance.

Tables 30 and 31 show the 100 seed weights due to the N, P, K and Mo main effects and the N, P, K interaction.

TABLE 30 : The Influence of N, P, K and Mo (Main effects) on 100 Seed Weight

Nutr. Level	Means of 48 Plants (g)		Means of 72 Plants (g)	
	N	K	P	Mo
1st	48.32 a	49.09 a	-	49.02 a
2nd	48.40 a	49.13 a	48.44 a	48.39 a
3rd	49.38 a	47.89 a	48.96 a	-

5% LSD 1.88 1.88 1.53 1.53

Data followed by different letters (a, b) are significantly different.

TABLE 31 : The Influence of N P K Interaction on 100 Seed Weight

Nutrient	Means of 8 Plants (g)		
	K_1	K_2	K_3
N_1 P_2	46.40 cd	48.61 bcd	47.82 bcd
P_3	52.30 ab	47.46 cd	47.36 cd
N_2 P_2	48.32 bcd	48.12 bcd	45.68 d
P_3	47.46 cd	50.48 abc	50.34 abc
N_3 P_2	53.92 a	50.28 abc	46.80 cd
P_3	46.09 cd	49.86 abcd	49.34 abcd

5% LSD = 4.60

Data followed by different letters (a, b, c, d) are significantly different.

It can be observed that the combinations N_3 P_2 K_1, N_1 P_3 K_1, N_2 P_3 K_2, N_2 P_3 K_3, N_3 P_2 K_2, produced seeds with a higher 100 seed weight than the average.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that from the nutrients examined only phosphorus had a main effect and from their interactions only the N P and N K significantly affected the germination percentage all at 1% level.

The germination percentages due to the main effects of N, P, K and Mo and the interactions of N P and N K are given in Tables 32, 33 and 34.

TABLE 32 : The Influence of N, P, K and Mo (Main effects) on Germination Percentage

Nutr. Level	Means of 36 Plants				Means of 54 Plants			
	N		K		P		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	71.10 a	89.51	73.10 a	91.55	-	-	72.90 a	91.35
2nd	69.40 a	87.62	72.10 a	90.55	78.30 a	95.89	70.40 a	88.75
3rd	74.40 a	92.77	69.80 a	88.08	65.00 b	82.14	-	-
5% LSD (for the angles)	5.23		5.23		4.27		4.27	

Data followed by different letters (a, b) within a column are significantly different.

It is therefore seen that the 2nd level of phosphorus significantly increased the percentage of germination compared with the 3rd level.

TABLE 33 : The Influence of N P Interaction on Germination Percentages

Nutr.	Means of 18 Plants			
	P_2		P_3	
	Angles	%	Angles	%
N_1	71.90 b	90.35	70.30 bc	88.64
N_2	77.60 b	95.39	61.20 d	76.79
N_3	85.30 a	99.33	63.50 cd	80.09

5% LSD = 7.41 (for the angles)
Data followed by different letters (a,b,c,d) are significantly different.

It can therefore be observed that the germination percentage increased with the combination N_3 P_2 followed by the N_2 P_2, N_1 P_2. The lowest germination percentage was obtained with the N_2 P_3 and N_3 P_3 combinations.

TABLE 34 : The Influence of N K Interaction on Germination Percentages

Nutr.	Means of 12 Plants					
	K_1		K_2		K_3	
	Angles	%	Angles	%	Angles	%
N_1	69.60 b	87.85	74.50 ab	92.86	69.30 bc	85.50
N_2	77.60 ab	95.39	70.20 b	88.53	60.40 c	75.60
N_3	72.20 ab	90.65	71.40 ab	89.83	79.60 a	96.74

5% LSD = 9.07 (for the angles)
Data followed by different letters (a,b,c) are significantly different.

The highest germination percentage was achieved with the combination N_3 K_3 and the lowest with the N_2 K_3; germination in all the other combinations was nearer to the highest percentage.

(b) Germination Rate

There were no significant differences in the germination rate between treatments. The germination rate values due to the main effects of N, P, K and Mo are given in Table 35.

TABLE 35 : The Influence of N, P, K and Mo (Main effects) on Germination Rate

Nutr. Level	Means of 36 Plants		Means of 54 Plants	
	N	K	P	Mo
1st	13.021 a	12.920 a	-	12.991 a
2nd	12.883 a	12.942 a	12.997 a	12.955 a
3rd	13.016 a	13.058 a	12.950 a	-
5% LSD	0.303	0.303	0.247	0.247

Data followed by different letters (a,b) within a column are significantly different.

(c) Seedling Mean Dry Weight

There were no significant differences between treatments on the seedling mean dry weight. The mean dry weights per seedling due to the main effects of N, P, K and Mo are given in Table 36.

TABLE 36 : The Influence of N, P, K and Mo (Main effects) on Mean Seedling Dry Weight

Nutr. Level	Means of 36 Plants		Means of 54 Plants	
	N	K	P	Mo
1st	0.312 a	0.316 a	-	0.312 a
2nd	0.315 a	0.313 a	0.312 a	0.315 a
3rd	0.313 a	0.311 a	0.315 a	-
5% LSD	0.014	0.014	0.011	0.011

Data followed by different letters (a,b) within a column are significantly different.

Seedling Evaluation Test

(a) Emergence Percentage

From the analysis of variance it was found that from the nutrients examined, only phosphorus significantly affected the emergence percentage at 1% level and from the interactions, the N P at 5% level and the N K Mo at 1% level of significance.

The emergence percentages due to the nutrient main effects and due to the N P and N K Mo interactions are given in Tables 37, 38 and 39.

TABLE 37 : The Influence of N, P, K and Mo (Main effects) on Emergence Percentage

Nutr. Level	Means of 48 Plants				Means of 72 Plants			
	N		K		P		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	64.40 a	81.33	64.83 a	81.91	-	-	66.54 a	84.15
2nd	63.46 a	80.03	62.80 a	79.11	69.18 a	87.37	63.20 a	79.67
3rd	66.75 a	84.42	66.97 a	84.69	60.55 b	75.83	-	-
5% LSD (for angles)	4.12		4.12		3.36		3.36	

Data followed by different letters (a,b) written within a column are significantly different.

It is therefore observed that the 2nd level of phosphorus significantly increased the percentage of emergence compared with the 3rd level.

TABLE 38 : The Influence of N P Interaction on Emergence Percentage

Nutr.	Means of 24 Plants			
	P_2		P_3	
	Angles	%	Angles	%
N_1	66.48 b	84.07	62.32 bc	78.42
N_2	66.85 b	84.54	60.06 c	75.09
N_3	74.23 a	92.61	59.27 c	73.89

5% LSD = 5.83 (for the angles)
Data followed by different letters (a,b,c) are significantly different.

It is therefore observed that the emergence percentage increased with the combination N_3 P_2. The lowest emergence percentage was achieved with the N_3 P_3 , N_2 P_3 combinations.

TABLE 39 : The Influence of N K Mo Interaction on Emergence Percentage

Nutrient	Means of 8 Plants			
	M_1		M_2	
	Angles	%	Angles	%
K_1	67.88 abcd	85.82	59.45 d	74.16
N_1 K_2	60.48 cde	75.72	61.95 bcde	77.89
K_3	62.63 bcde	78.86	74.00 a	92.40
K_1	67.73 abcd	85.64	64.65 abcd	81.67
N_2 K_2	61.99 bcde	77.94	61.04 cde	76.55
K_3	71.93 ab	90.38	53.38 c	64.42
K_1	65.80 abcd	83.20	63.45 bcde	80.02
N_3 K_2	69.81 abc	88.09	61.54 cde	77.29
K_3	70.54 abc	88.90	69.33 abcd	87.54

5% LSD = 10.09 (for the angles)

Data followed by different letters (a,b,c,d,e) are significantly different.

The highest percentages were achieved by the combination N_1 K_3 M_2 followed by N_2 K_3 M_1 , N_3 K_3 M_1 , N_3 K_2 M_1 and N_3 K_3 M_2 combinations.

(b) Emergence Rate

Only the potassium main effect was found to be significant at 1% level on seedling emergence rate.

In Table 40 the values of seedling emergence rate due to the N, P, K and Mo main effects are given:

TABLE 40 : The Influence of N, P, K, Mo (Main effects) on Seedling Emergence Rate

Nutr. Level	Means of 48 Plants		Means of 72 Plants	
	N	K	P	Mo
1st	10.905 a	10.778 b	-	10.883 a
2nd	10.915 a	10.796 b	10.922 a	10.840 a
3rd	10.765 a	11.010 a	10.801 a	-
5% LSD	0.163	0.163	0.133	0.133

Data followed by different letters (a, b) within a column are significantly different.

It can therefore be observed that the 3rd level of potassium gave the highest emergence rate followed by the 2nd and 1st levels which gave values not significantly different (K_3, $\underline{K_2, K_1}$).

(c) Seedling Dry Weight

Only the nitrogen main effect was found to be significant on seedling mean dry weight at the 1% level.

The dry weights per seedling due to the N, P, K and Mo main effects are given in Table 41.

TABLE 41 : The Influence of N, P, K and Mo (Main effects) on Seedling Dry Weight

Nutr. Level	Means of 48 Plants (g)		Means of 72 Plants (g)	
	N	K	P	Mo
1st	0.225 b	0.226 a	-	0.233 a
2nd	0.226 b	0.236 a	0.233a	0.228 a
3rd	0.241 a	0.230 a	0.228 a	-
5% LSD	0.011	0.011	0.009	0.009

Data followed by different letters (a, b) within a column are significantly different.

It can be observed that the 3rd level of nitrogen produced the heaviest seedlings and is followed by the 2nd and 1st levels which produced seedlings with mean dry weights not significantly different.

(d) Percentage of Very Weak Seedlings

Only the effects of phosphorus and of the N, K interaction on the percentage of very weak seedlings were found to be significant at the 5% level. Table 42 and 43 give these percentages due to the main effects N,P,K and Mo and due to the N,K interaction.

TABLE 42 : The Influence of N, P, K and Mo (Main effects) on Percentage of Very Weak Seedlings

Nutr. Level	Means of 48 Plants				Means of 72 Plants			
	N		K		P		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	7.07 a	1.51	5.63 a	0.96	-	-	5.79 a	1.02
2nd	5.97 a	1.08	6.46 a	1.26	4.41 b	0.59	5.70 a	0.99
3rd	4.19 a	0.53	5.14 a	0.80	7.08 a	1.52	-	-

5% LSD 2.98 2.98 2.43 2.43
(for angles)

Data followed by different letters (a, b) within a column are significantly different.

It can be observed that the 3rd level of phosphorus produced a larger percentage of very weak seedlings than the 2nd level.

TABLE 43 : The Influence of N, K Interaction on Percentage of Very Weak Seedlings

Nutr.	Means of 16 Plants					
	K_1		K_2		K_3	
	Angles	%	Angles	%	Angles	%
N_1	5.35 b	0.87	11.75 a	4.15	4.13 b	0.52
N_2	5.80 b	1.02	5.40 b	0.89	6.71 ab	1.36
N_3	5.75 b	1.00	2.22 b	0.15	4.60 b	0.64

5% LSD = 5.16 (for the angles)

Data followed by different letters (a, b) are significantly different.

It can be observed that the only combination which produced a larger percentage of very weak seedlings was N_1 K_2.

(e) Percentage of Weak Seedlings

Only the effects of the N,P interaction on the percentage of weak seedlings were found to be significant at the 1% level. Tables 44 and 45 give these percentages due to N,P,K and Mo main effects and due to N,P interaction.

TABLE 44 : The Influence of N, P, K and Mo (Main effects) on Percentage of Weak Seedlings

Nutr. Level	Means of 48 Plants				Means of 72 Plants			
	N		K		P		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	27.43 a	21.22	27.25 a	20.96	-	-	25.23 a	18.17
2nd	26.07 a	19.31	25.61 a	18.68	26.36 a	19.71	27.43 a	21.22
3rd	25.48 a	18.51	26.12 a	19.38	26.29 a	19.62	-	-

5% LSD 3.19 3.19 2.61 2.61
(for the angles)

Data followed by different letters (a,b) within a column are significantly different.

TABLE 45 : The Influence of N, P Interaction on Percentage of Weak Seedlings

Nutr.	Means of 24 Plants			
	P_2		P_3	
	Angles	%	Angles	%
N_1	27.30 abc	21.04	27.57 ab	21.42
N_2	28.82 a	23.24	23.31 bc	15.66
N_3	22.97 c	15.23	27.98 a	22.01

5% LSD = 4.51 (for the angles)

Data followed by different letters (a,b,c) are significantly different.

It can be observed that a higher amount of weak seedlings were produced with the combinations N_2 P_2, N_3 P_3, N_1 P_3.

(f) Percentage of Vigorous Seedlings

It was found that only molybdenum and the N, P interaction had significant effects on the percentage of vigorous seedlings at the 5% and 1% levels respectively.

Tables 46 and 47 give the percentages due to the main effects of N, P, K and Mo and due to N, P interaction.

TABLE 46 : The Influence of N, P, K and Mo (Main effects) on Percentage of Vigorous Seedlings

Nutr. Level	Means of 48 Plants				Means of 72 Plants			
	N		K		P		Mo	
	Angles	%	Angles	%	Angles	%	Angles	%
1st	60.39 a	75.69	61.35 a	77.01	-	-	63.33 a	79.85
2nd	61.53 a	77.28	61.99 a	77.94	62.71 a	78.98	60.40 b	75.60
3rd	63.68 a	80.34	62.27 a	78.35	61.03 a	76.54	-	-
5% LSD (for angles)	3.38		3.38		2.76		2.76	

Data followed by different letters (a,b) within a column are significantly different.

TABLE 47 : The Influence of N, P Interaction on the Percentage of Vigorous Seedlings

Nutr.	Means of 24 Plants			
	P_2		P_3	
	Angles	%	Angles	%
N_1	61.30 b	76.94	59.48 b	74.21
N_2	59.76 b	74.64	63.30 ab	79.81
N_3	67.06 a	84.81	60.31 b	75.47

5% LSD = 4.78
(for angles)

Data followed by different letters (a,b) are significantly different.

It can be observed that only the combination N_3 P_2 produced more vigorous seedlings than the others.

Experiment No. 2

Plant Growth

From the very early stages, all the plants which were receiving treatments containing the lowest level of phosphorus (P_1), were growing slower than plant receiving the other treatments and they remained relatively smaller throughout the experiment (Plate 1).

By the end of flowering, the leaf colour of all the plants receiving treatments with the lowest level of nitrogen (N_1) appeared to be lighter than the other plants.

From the flowering period and during the pod development plants receiving the lowest level of potassium (K_1) started to show marginal and later interveinal chlorosis and finally marginal scorching in the top leaves (Plate 2). These symptoms appeared first in plants receiving the treatment N_3 P_3 K_1, then in plants receiving the treatment N_3 P_2 K_1, followed by plants receiving treatments N_2 P_3 K_1 and N_2 P_3 K_1 and finally by plants receiving the treatments N_1 P_3 K_1 and N_1 P_2 K_1 (Plates 3 and 4).

After harvesting the dry matter of stems (without leaves) per plant was measured. From the analysis of variance it was found that all the nutrient levels significantly affected, at 1% level of significance, the stem dry matter. Also the interactions PK and NP significantly affected the stem dry matter at 1% level.

The mean stem dry matter weights per plant and per nutrient level are given in Table 48.

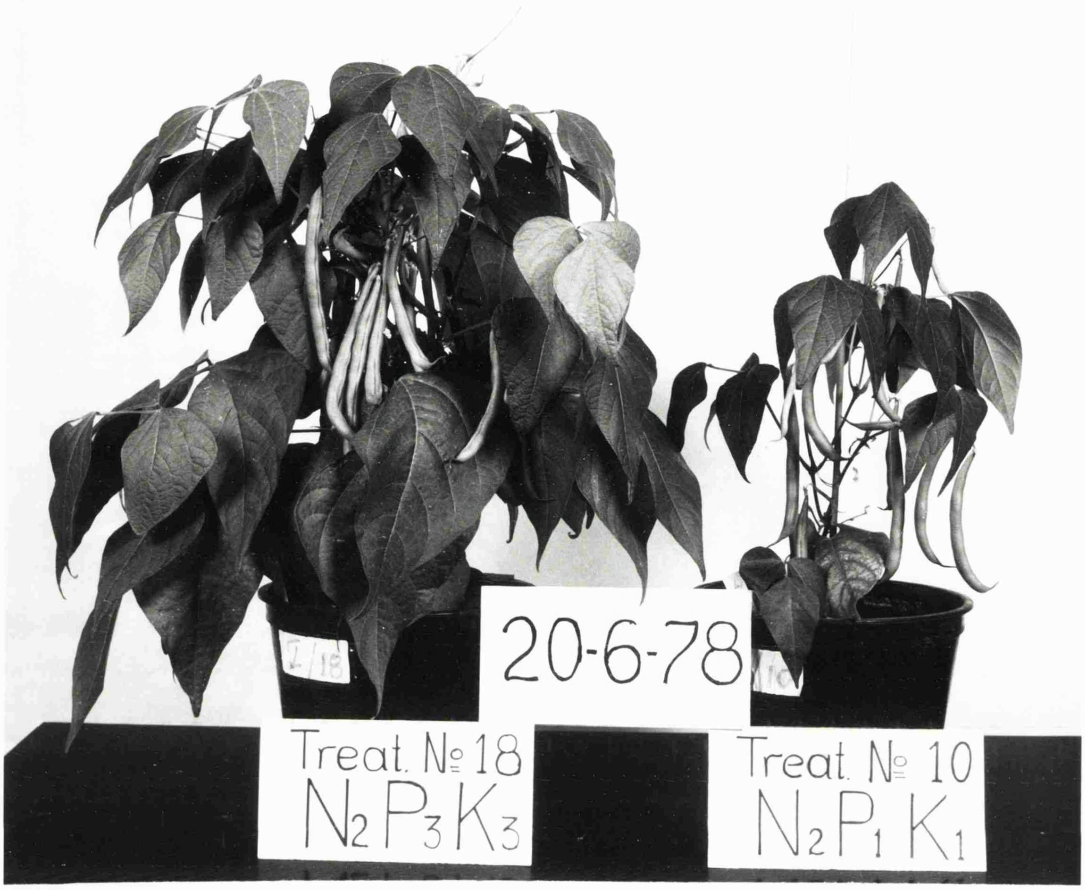

PLATE I : The Effect of the Nutritional Treatments (Low Phosphorus) on Plant Growth (Experiment No.2)

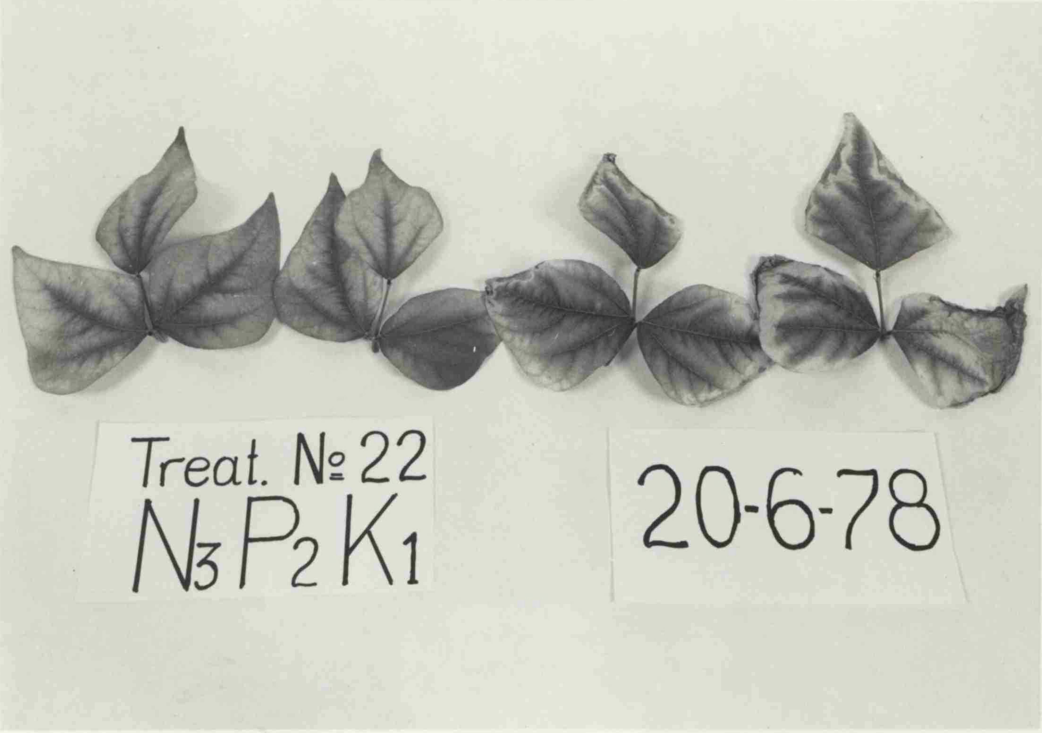

PLATE 2 : Deficiency Symptoms on Bean Leaves from Plants Treated with Low Potassium Fertilizers (Experiment No.2)

PLATE 3 : Deficiency Symptoms on Bean Plants Receiving Nutrient Combinations Low in Potassium (Experiment No.2)

PLATE 4 : Deficiency Symptoms on Bean Plants Receiving Nutrient Combinations Low in Potassium (Experiment No.2)

TABLE 48 : The Influence of N, P and K (Main effects) on Stem Dry Matter Weight

Nutrient Level	Means of 72 Plants (g)		
	N	P	K
1st	4.912 b	2.505 c	5.053 c
2nd	7.227 a	7.695 b	6.362 b
3rd	6.913 a	8.852 a	7.636 a
5% LSD	0.335	0.335	0.335

Data followed by different letters (a, b, c) within a column are significantly different.

It was therefore observed that from the nitrogen levels the 2nd nutrient level gave plants with the highest dry matter. This value is significantly different from the value due to the 1st level of nitrogen but not from the value due to the 3rd level of nitrogen. With the 3rd level of nitrogen a small decline in stem dry matter is observed ($\underline{N_2, N_3}$, N_1). The 3rd phosphorus level gave the highest stem dry matter followed respectively by the 2nd and 1st levels ($P_3 > P_2 > P_1$). From the potassium levels the 3rd gave the highest stem dry matter, followed respectively by the 2nd and 1st levels ($K_3 > K_2 > K_1$).

The values of stem dry matter per plant resulting from the interaction between the phosphorus and potassium levels are given in Table 49.

TABLE 49 : The Influence of PK Interaction on Stem Dry Matter

Nutrient	Means of 24 Plants (g)		
	K_1	K_2	K_3
P_1	2.339 e	2.318 e	2.860 e
P_2	6.290 d	7.671 c	9.122 b
P_3	6.530 d	9.097 b	10.927 a

5% LSD = 0.581

Data followed by different letters (a,b,c,d,e) are significantly different.

From this table it can be observed that the highest stem dry matter was achieved by the P_3 K_3 combination followed by the P_2 K_3, P_3 K_2, P_2 K_2.

The values of stem dry matter per plant due to the interaction between the nitrogen and phosphorus levels are given in Table 50.

TABLE 50 : The Influence of NP Interaction on Stem Dry Matter

Nutrient	Means of 24 Plants (g)		
	P_1	P_2	P_3
N_1	2.432 fg	5.078 e	7.225 d
N_2	2.970 f	9.066 bc	9.645 ab
N_3	2.115 g	8.940 c	9.684 a

5% LSD = 0.581

Data followed by different letters (a-g) are significantly different.

From this table it is observed that the highest stem dry matter was achieved from the N_3 P_3 and N_2 P_3 combinations. The values of stem dry matter due to these two combinations are not significantly different. The second best values were achieved from the N_2 P_2 and N_3 P_2 without significant difference between them.

Days to First Flower

There is evidence that the number of days from sowing to first flower is only affected by the phosphorus levels. The mean number of days from sowing to first flower per nutrient level are given in Table 51.

TABLE 51 : The Influence of N, P and K (Main effects) on Mean Days to First Flower

Nutrient Levels	Means of 72 Plants (Days)		
	N	P	K
1st	43.819 a	44.639 b	44.153 a
2nd	44.056 a	43.899 a	43.896 a
3rd	44.306 a	43.653 a	44.042 a
5% LSD	0.451	0.451	0.451

Data followed by different letters (a,b) within a column are significantly different.

It is therefore observed that the first level of phosphorus delayed the first flower compared with the other two levels, but in practice this delay is not important because it is less than one day.

Mean Days to Harvest

The mean days from sowing to harvesting were calculated. The analysis of variance for these figures showed that the nitrogen and potassium levels significantly affected the time from sowing to harvesting, (nitrogen at 5% level, potassium at 1% level of significance). Also the interaction NP and PK affected this duration significantly at 1% level.

The mean time from sowing to harvest due to the N, P and K main effects and due to NP and PK interactions are shown in Tables 52, 53 and 54.

TABLE 52 : The Influence of N, P and K (Main effects) on the Mean Time to Harvest

Nutrient Level	Means of 72 Plants (Days)		
	N	P	K
1st	93.346 b	93.463 a	93.253 b
2nd	93.624 a	93.487 a	93.614 a
3rd	93.486 ab	93.506 a	93.590 a

5% LSD	0.186	0.186	0.186

Data followed by different letters (a, b) within a column are significantly different.

TABLE 53 : The Influence of NP Interaction on the Mean Time to Harvest

Nutrient Level	Means of 24 Plants (Days)		
	N	P	K
1st	93.536 ab	93.167 c	93.335 bc
2nd	93.703 a	93.580 ab	95.589 ab
3rd	93.150 c	93.715 a	93.595 ab

5% LSD = 0.322

Data followed by different letters (a,b,c) are significantly different.

TABLE 54 : The Influence of PK Interaction on the Mean Time to Harvest

Nutrient	Means of 24 Plants (Days)		
	K_1	K_2	K_3
P_1	93.711 a	93.347 bc	93.332 bc
P_2	93.177 cd	93.699 a	93.586 ab
P_3	92.870 d	93.797 a	93.851 a

5% LSD = 0.322

Data followed by different letters (a,b,c,d) are significantly different.

Although the differences of these values were found to be highly significant, in practice this is not important, as their differences are less than one day.

Number of Pods Per Plant

It was found from the analysis of variance that all the nutrients examined, significantly affected the number of pods per plant at 1% level of significance. In addition all the interactions between N, P, K significantly affected the number of pods per plant, the NP, NK, PK at 1% level and NPK at 5% level of signficance.

The mean number of pods per plant due to the main effects of nitrogen, phosphorus and potassium are given in Table 55.

TABLE 55 : The Influence of N, P and K (Main effects) on Mean Number of Pods Per Plant

Nutrient Level	Means of 72 Plants		
	N	P	K
1st	17.04 b	10.31 c	17.03 c
2nd	22.46 a	24.35 b	21.06 b
3rd	21.72 a	26.56 a	23.07 a
5% LSD	1.01	1.01	1.01

Data followed by different letters (a,b,c) within a column are significantly different.

It was therefore found that in the case of nitrogen both the 2nd and 3rd levels significantly increased the number of pods per plant compared with the 1st level, ($\underline{N_2, N_3}, N_1$). In the case of phosphorus and potassium their 3rd levels gave the highest number of pods per plant followed respectively by the 2nd and 1st levels ($P_3 > P_2 > P_1$), ($K_3 > K_2 > K_1$).

The mean number of pods per plant due to the NP interaction are given in Table 56.

TABLE 56 : The Influence of NP Interaction on Mean Number of Pods Per Plant

Nutrient	Means of 24 Plants		
	P_1	P_2	P_3
N_1	9.46 f	19.54 d	22.12 c
N_2	12.33 e	26.29 b	28.75 a
N_3	9.15 f	27.21 ab	28.79 a

5% LSD = 1.75

Data followed by different letters (a-f) are significantly different.

It can be observed that the combinations N_3P_3, $N_2\ P_3$ gave the highest number of pods per plant followed by the combinations $N_3\ P_2$, $N_2\ P_2$. The lowest number of pods per plant was produced by the combinations $N_1\ P_1$, $N_2\ P_1$, $N_3\ P_1$.

The mean number of pods per plant due to the NK interaction is given in Table 57.

TABLE 57 : The Influence of NK Interaction on Mean Number of Pods Per Plant

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
N_1	15.37 e	16.29 de	19.46 c
N_2	17.92 cd	23.75 b	25.71 a
N_3	17.96 cd	23.15 b	24.04 ab

5% LSD = 1.75

Data followed by different letters (a-e) are significantly different.

The combinations which gave the highest number of pods per plant are N_2 K_3, N_3 K_3 followed by the combinations N_2 K_2, N_3 K_2. The lowest number of pods per plant was produced by the combinations N_1 K_1, N_1 K_2.

The mean number of pods per plant due to the interaction PK are given in Table 58.

TABLE 58 : The Influence of PK Interaction on Mean Number of Pods Per Plant

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
P_1	9.96 e	9.94 e	11.04 e
P_2	20.37 d	24.50 c	28.17 b
P_3	20.92 d	28.75 ab	30.00 a

5% LSD = 1.75

Data followed by different letters (a-e) are significantly different.

The combinations which gave the highest number of pods per plant are P_3 K_3, P_3 K_2 followed by the combinations P_2 K_3, P_2 K_2. The lowest number of pods per plant were produced by the combinations P_1 K_1, P_1 K_2, P_1 K_3.

The mean number of pods per plant due to the interaction N P K are given in Table 59.

TABLE 59 : The Influence of NPK Interaction on Mean Number of Pods Per Plant

Nutrient	Means of 8 Plants (g)		
	K_1	K_2	K_3
P_1	9.75 kl	8.50 l	10.12 kl
N_1 P_2	18.25 gh	16.25 hi	24.12 e
P_3	18.12 gh	24.12 e	24.12 e
P_1	11.25 jkl	11.75 jk	14.00 ij
N_2 P_2	20.12 fg	29.00 cd	29.75 bcd
P_3	22.37 ef	30.50 abcd	33.37 a
P_1	8.87 kl	9.57 kl	9.00 kl
N_3 P_2	22.75 ef	28.25 d	30.62 abcd
P_3	22.25 ef	31.62 abc	32.50 ab

5% LSD = 3.04

Data followed by different letters (a-l) are significantly different.

Examining this table it can be observed that more pods were produced by plants receiving the combinations N_2 P_3 K_3, N_3 P_3 K_3, N_3 P_3 K_2, N_3 P_2 K_3, N_2 P_3 K_2, and lower numbers of pods were produced by plants receiving the combinations N_1 P_1 K_2, N_3 P_1 K_1, N_3 P_1 K_3, N_3 P_1 K_2, N_1 P_1 K_1, N_1 P_1 K_3, N_2 P_1 K_1, N_2 P_1 K_2, N_2 P_1 K_3.

Number of Seeds Per Plant

It was found from the analysis of variance that, as in the case of the number of pods per plant, all the nutrients examined and all their interactions significantly affected the number of seeds per plant at 1% level of significance.

The mean number of seeds per plant due to the main effects of nitrogen, phosphorus and potassium, and due to their interactions are given in Tables 60, 61, 62, 63 and 64.

TABLE 60 : The Influence of N, P, K (Main effects) on Mean Number of Seeds Per Plant

Nutrient Levels	Means of 72 Plants		
	N	P	K
1st	68.61 c	40.90 c	60.90 c
2nd	91.54 a	97.56 b	87.69 b
3rd	85.58 b	107.28 a	97.14 a
5% LSD	4.71	4.71	4.71

Data followed by different letters (a,b,c) within a column are significantly different.

It was therefore found that in the nitrogen treatments the 2nd level produced the highest number of seeds per plant followed respectively by the 3rd and 1st levels. With phosphorus and potassium their 3rd levels produced the highest numbers of seeds followed respectively by the 2nd and 1st levels ($N_2 > N_3 > N_1$), ($P_3 > P_2 > P_1$), ($K_3 > K_2 > K_1$).

TABLE 61 : The Influence of NP Interaction on Mean Number of Seeds Per Plant

Nutrient	Means of 24 Plants		
	P_1	P_2	P_3
N_1	34.50 f	78.54 d	92.79 c
N_2	49.46 e	105.25 b	119.92 a
N_3	38.74 f	108.87 b	109.12 b

5% LSD = 8.15

Data followed by different letters (a-f) are significantly different.

It can be observed that the combination N_2 P_3, produced the highest number of seeds per plant, followed by the combinations N_3 P_3, N_3 P_2, N_2 P_2. The lowest number of seeds per plant was produced by the combinations N_1 P_1, N_3 P_1 and N_2 P_1.

TABLE 62 : The Influence of NK Interaction on Mean Number of Seeds Per Plant

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
N_1	60.12 e	68.46 d	77.25 c
N_2	63.50 de	99.25 b	111.87 a
N_3	59.08 e	95.36 b	102.29 b

5% LSD = 8.15

Data followed by different letters (a-e) are significantly different.

The combination which produced the highest number of seeds per plant is N_2 K_3 followed by the N_3 K_3, N_2 K_2, N_3 K_2. The lowest number of seeds per plant was produced by the combinations N_3 K_1, N_1 K_1, N_2 K_1.

TABLE 63 : The Influence of PK Interaction on the Mean Number of Seeds Per Plant

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
P_1	36.21 e	40.41 de	46.08 d
P_2	71.37 c	102.29 b	119.00 a
P_3	75.12 c	120.37 a	126.33 a

5% LSD = 8.15

Data followed by different letters (a-e) are significantly different.

The combinations which gave the highest number of pods per plant are P_3 K_3, P_3 K_2, P_2 K_3 and the lowest P_1 K_1, P_1 K_2, P_1 K_3.

TABLE 64 : The Influence of N P K Interaction on Mean Number of Seeds Per Plant

Nutrient	Means of 8 Plants (g)		
	K_1	K_2	K_3
P_1	33.75 i	32.37 i	37.39 i
N_1 P_2	71.25 gh	68.75 h	95.62 ef
P_3	75.37 gh	104.25 e	98.75 e
P_1	40.75 i	45.38 i	62.25 h
N_2 P_2	66.87 h	119.37 cd	129.50 bcd
P_3	82.87 fg	133.00 abc	143.87 a
P_1	34.12 i	43.47 i	38.62 i
N_3 P_2	76.00 gh	118.75 d	131.87 abcd
P_3	67.12 h	123.87 bcd	136.37 ab

5% LSD = 14.12

Data followed by different letters (a-i) are significantly different.

Examining this table it can be observed that more seeds were produced by plants receiving the combinations N_2 P_3 K_3, N_3 P_3 K_3, N_2 P_3 K_2, N_3 P_2 K_3, N_2 P_2 K_3, N_3 P_3 K_2, N_2 P_2 K_2, N_3 P_2 K_2, and lower numbers of seeds were produced by plants receiving the combinations N_1 P_1 K_2, N_1 P_1 K_1, N_3 P_1 K_1, N_1 P_1 K_3, N_3 P_1 K_3, N_2 P_1 K_1, N_3 P_1 K_2, N_2 P_1 K_2.

Number of Seeds Per Pod

It was found from the analysis of variance that of the nutrients examined, only potassium had a significant effect on the number of seeds per pod, and from their interactions N P and NK all at 1% level.

Tables 65, 66 and 67 show these effects on the number of seeds per pod.

TABLE 65 : The Influence of N, P and K (Main effects) on Mean Number of Seeds Per Pod

Nutrient Levels	Means of 72 Plants		
	N	P	K
1st	3.997 a	3.981 a	3.623 b
2nd	4.036 a	4.003 a	4.178 a
3rd	3.975 a	4.023 a	4.207 a
5% LSD	0.178	0.178	0.178

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that only the lowest level of potassium gave a smaller number of seeds per pod than the levels K_2 and K_3, but since these differences are less than 1, which is the smallest difference in seeds per pod, the effect of potassium on the number of seeds per pod it is, in practice, not important.

TABLE 66 : The Influence of NP Interaction on Mean Number of Seeds Per Pod

Nutrient	Means of 24 Plants		
	P_1	P_2	P_3
N_1	3.722 b	4.059 a	4.209 a
N_2	3.994 ab	3.970 ab	4.143 a
N_3	4.228 a	3.981 ab	3.716 b

5% LSD = 0.309

Data followed by different letters (a,b) are significantly different.

The combinations which produced the highest number of seeds per pod are N_3 P_1, N_1 P_3, N_2 P_3, N_1 P_2 and lower number of seeds per pod were produced by combinations N_3 P_3, N_1 P_1.

TABLE 67 : The Influence of NK Interaction on Mean Number of Seeds Per Pod

Nutrient	Means of 24 Plants		
	K_1	K_2	K_3
N_1	3.894 c	4.151 abc	3.945 bc
N_2	3.564 d	4.155 abc	4.388 a
N_3	3.411 d	4.228 ab	4.287 a

5% LSD = 0.309

Data followed by different letters (a,b,c) are significantly different.

The combinations which gave the highest number of seeds per pod are N_2 K_3, N_3 K_3, the lower number of seeds per pod resulted from N_3 K_1 and N_2 K_1 combinations.

Seed Yield

It was found from the analysis of variance that all the nutrients examined and all their interactions significantly affected the seed yield per plant at 1% level. The mean seed yield per plant due to the main effects of nitrogen, phosphorus and potassium and due to their interactions are given in Tables 68, 69, 70, 71 and 72.

TABLE 68 : The Influence of N, P and K (Main effects) on Mean Seed Yield Per Plant

Nutrient Levels	Means of 72 Plants (g)		
	N	P	K
1st	31.75 b	19.33 c	26.81 c
2nd	41.46 a	45.60 b	41.18 b
3rd	40.20 a	48.48 a	45.41 a
5% LSD	1.82	1.82	1.82

Data followed by different letters (a,b,c) within a column are significantly different.

It was therefore found that in the case of nitrogen both the 2nd and 3rd levels significantly increased the seed yield compared with the 1st level, in the case of phosphorus and potassium their 3rd levels gave the highest seed yield followed respectively by the 2nd and 1st levels $(\underline{N_2\ N_3}\ N_1)$, $(P_3 > P_2 > P_1)$, $(K_3 > K_2 > K_1)$.

TABLE 69 : The Influence of NP Interaction on Mean Seed Yield Per Plant

Nutrient	Means of 24 Plants (g)		
	P_1	P_2	P_3
N_1	15.88 g	36.24 e	43.12 d
N_2	23.43 f	48.17 c	52.27 a
N_3	18.67 g	52.39 ab	49.54 bc

5% LSD = 3.15

Data followed by different letters (a-g) are significantly different.

It can be observed that the combinations N_2 P_3, N_3 P_2 gave the highest seed yield per plant followed by the combinations N_3 P_3, N_2 P_2. The lowest seed yield per plant was produced by the combinations N_1 P_1, N_3 P_1, N_2 P_1.

TABLE 70 : The Influence of NK Interaction on Mean Seed Yield Per Plant

Nutrient	Means of 24 Plants (g)		
	K_1	K_2	K_3
N_1	25.01 g	33.20 e	37.03 d
N_2	28.43 f	45.02 c	50.92 a
N_3	26.99 fg	45.32 bc	48.28 ab

5% LSD = 3.15

Data followed by different letters (a-g) are significantly different.

The combinations which gave the highest seed yield per plant are N_2K_3, $N_3\ K_3$ followed by the combinations $N_3\ K_2$, $N_2\ K_2$. The lowest seed yield per plant was produced by the combinations $N_1\ K_1$, $N_3\ K_1$, $N_2\ K_1$.

TABLE 71 : The Influence of PK Interaction on Mean Seed Yield Per Plant

Nutrient	Means of 24 Plants (g)		
	K_1	K_2	K_3
P_1	17.77 e	19.18 de	21.03 d
P_2	32.17 c	48.23 b	56.39 a
P_3	30.48 c	56.13 a	58.82 a

5% LSD = 3.15

Data followed by different letters (a-e) are significantly different.

The combinations which gave the highest seed yield per plant are $P_3\ K_3$, $P_2\ K_3$, $P_3\ K_2$ and those which gave the lowest seed yield per plant are $P_1\ K_1$, $P_1\ K_2$, $P_1\ K_3$.

TABLE 72 : The Influence of N, P, K Interaction on Mean Seed Yield Per Plant

Nutrient		Means of 8 Plants (g)		
		K_1	K_2	K_3
	P_1	15.70 no	14.31 o	17.63 mno
N_1	P_2	29.43 ijk	33.21 hij	46.07 g
	P_3	29.90 ijk	52.07 ef	47.39 fg
	P_1	21.05 mn	22.08 lm	27.15 kl
N_2	P_2	30.57 ijk	54.69 de	59.24 bcd
	P_3	33.66 hi	58.29 cd	66.37 a
	P_1	16.58 no	21.13 mn	18.30 mno
N_3	P_2	36.52 h	56.78 de	63.86 ab
	P_3	27.88 jk	58.04 cd	62.69 abc

5% LSD = 5.45

Data followed by different letters (a-o) are significantly different.

Examining this table it can be observed that higher seed yield were produced by plants receiving the combinations N_2 P_3 K_3, N_3 P_2 K_3, N_3 P_3 K_3, N_2 P_2 K_3 and lower seed yields were produced by plants receiving the combinations N_1 P_1 K_2, N_1 P_1 K_1, N_3 P_1 K_1, N_1 P_1 K_3, N_3 P_1 K_3.

Seed to Empty Pod Ratio (S:EP)

From the analysis of variance it has been found that this ratio was significantly affected by the phosphorus and potassium at 1% level of significance. It was also significantly affected by the interaction between nitrogen and phosphorus levels at the same level of significance.

The mean values of S:EP ratio due to the main effects of nitrogen, phosphorus and potassium and due to the NP interaction are given in Tables 73 and 74.

TABLE 73 : The Influence of N, P and K (Main effects) on the Mean S:EP Ratio

Nutrient Levels	Means of 72 Plants		
	N	P	K
1st	2.989 a	2.699 b	3.203 a
2nd	2.967 a	3.106 a	2.996 b
3rd	3.045 a	3.196 a	2.802 c
5% LSD	0.141	0.141	0.141

Data followed by different letters (a,b,c) within a column are significantly different.

It is therefore observed that the P_2 and P_3 levels both gave a better ratio than the P_1 level ($\underline{P_3, P_2}, P_1$). The K_1 level also gave a better ratio, followed respectively by the K_2 and K_3 levels ($K_1 > K_2 > K_3$).

TABLE 74 : The Influence of NP Interaction on Mean S:EP Ratio

Nutrient	Means of 24 Plants		
	P_1	P_2	P_3
N_1	2.439 e	3.241 ab	3.287 a
N_2	2.697 d	2.939 cd	3.263 ab
N_3	2.960 c	3.137 abc	3.039 bc

5% LSD = 0.244

Data followed by different letters (a,b,c,d,e) within a column are significantly different.

The best S:EP ratio was achieved by the N_1 P_3, N_2 P_3 combinations, followed by the N_1 P_2, N_3 P_2, N_3 P_3.

The worst S:EP ratio was achieved by the combination N_1 P_1.

Seed Size Determination

(a) Weight of Individual Seeds

The mean seed weight per treatment has been calculated as in Experiment No. 1. From the analysis of variance it was found that the mean seed weight was affected by the phosphorus and potassium levels at 1% level, by the interactions, NP, NK, PK at 1% level and the interaction NPK at 5% level.

Tables 75, 76, 77, 78 and 79 give the mean seed weight values due to the main effects of N, P and K and due to all their possible interactions.

TABLE 75 : The Influence of N, P and K (Main effects) on Mean Seed Weight

Nutrient Levels	Means of 72 Plants (g)		
	N	P	K
1st	0.462 a	0.476 a	0.454 b
2nd	0.462 a	0.469 a	0.474 a
3rd	0.474 a	0.454 b	0.470 a
5% LSD	0.012	0.012	0.012

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that in the case of phosphorus, the highest seed weight was achieved with the 1st and 2nd levels followed by the 3rd level ($\underline{P_1\ P_2}\ P_3$), and in the case of potassium the 2nd and 3rd levels gave the highest seed weight and the 1st levels the lowest ($\underline{K_2,\ K_3},\ K_1$).

TABLE 76 : The Influence of NP Interaction on Mean Seed Weight

Nutrient	Means of 24 Plants (g)		
	P_1	P_2	P_3
N_1	0.460 c	0.462 c	0.464 bc
N_2	0.484 ab	0.457 c	0.445 c
N_3	0.483 ab	0.487 a	0.452 c

5% LSD = 0.021

Data followed by different letters (a,b,c) are significantly different.

From this table it can be observed that the highest seed weight was achieved with the combination N_3 P_2 followed by the combinations N_2 P_1, N_3 P_1.

TABLE 77 : The Influence of NK Interaction on Mean Seed Weight

Nutrient	Means of 24 Plants (g)		
	K_1	K_2	K_3
N_1	0.427 d	0.478 ab	0.480 ab
N_2	0.471 abc	0.462 bc	0.454 c
N_3	0.464 abc	0.483 a	0.475 ab

5% LSD = 0.021

Data followed by different letters (a,b,c,d) are significantly different.

From Table 77 it can be seen that heavier seeds were produced with the combinations N_3 K_2, N_1 K_3, N_1 K_2, N_3 K_3, N_2 K_1, N_3 K_1 and the lighter seeds with the combination N_1 K_1.

TABLE 78 : The Influence of PK Interaction on Mean Seed Weight

Nutrient	Means of 24 Plants (g)		
	K_1	K_2	K_3
P_1	0.492 a	0.473 ab	0.462 b
P_2	0.457 b	0.473 ab	0.476 ab
P_3	0.413 c	0.477 ab	0.471 b

5% LSD = 0.021

Data followed by different letters (a,b,c) are significantly different.

The heavier seeds were produced with the combinations P_1 K_1, P_3 K_2, P_2 K_3, P_2 K_2, P_1 K_2 and the lightest with the combination P_3 K_1.

TABLE 79 : The Influence of N P K Interaction on Mean Seed Weight

Nutrient	Means of 8 Plants (g)		
	K_1	K_2	K_3
N_1 P_1	0.466 cdef	0.441 fgh	0.473 bcdef
N_1 P_2	0.414 hi	0.487 abc	0.484 bcd
N_1 P_3	0.402 i	0.506 ab	0.484 bcd
N_2 P_1	0.522 a	0.490 abc	0.442 efgh
N_2 P_2	0.468 cdef	0.447 efgh	0.457 cdefg
N_2 P_3	0.422 ghi	0.449 defgh	0.464 cdef
N_3 P_1	0.489 abc	0.489 abc	0.472 bcdef
N_3 P_2	0.488 abc	0.485 bc	0.488 abc
N_3 P_3	0.416 hi	0.477 bcde	0.465 cdef

5% LSD = 0.036

Data followed by different letters (a-h) are signficantly different.

It can be seen from this table that heavier seeds were produced with the combinations N_2 P_1 K_1, N_1 P_3 K_2, N_2 P_1 K_2, N_3 P_1 K_1, N_3 P_1 K_2, N_3 P_2 K_1, N_3 P_2 K_3, N_1 P_2 K_2 and the lighter with the combinations N_1 P_3 K_1, N_1 P_2 K_1, N_3 P_3 K_1, N_2 P_3 K_1.

(b) <u>100 Seed Weight</u>

The analysis of variance showed that all nutrients examined and all their interactions significantly affected the 100 seed weight at 1% level. Tables 80, 81, 82, 83 and 84 show the values of the 100 seed weight as affected by the N, P, K and by their interactions.

TABLE 80 : The Influence of N, P and K (Main effects) on 100 Seed Weight

Nutrient Levels	Means of 90 Plants (g)		
	N	P	K
1st	45.27 b	46.44 a	44.48 b
2nd	44.90 b	45.88 b	46.43 a
3rd	46.71 a	44.57 c	45.99 a
5% LSD	0.55	0.55	0.55

Data followed by different letters (a,b,c) within a column are significantly different.

It can be observed that in the case of nitrogen the 3rd level produced higher 100 seed weight followed by the 1st and 2nd levels which produced seeds with similar 100 seed weight. In the case of phosphorus the 1st level produced the highest 100 seed weight which is decreased with the increase of phosphorus. In the case of potassium the 2nd and 3rd levels produced higher 100 seed weight than the 1st level.

TABLE 81 : The Influence of NP Interaction on 100 Seed Weight

Nutrient	Means of 30 Plants (g)		
	P_1	P_2	P_3
N_1	45.20 b	45.48 b	45.12 b
N_2	46.81 a	44.61 b	43.30 c
N_3	47.31 a	47.54 a	45.28 b

5% LSD = 0.957

Data followed by different letters (a,b,c) are significantly different.

Therefore the highest 100 seed weight was obtained with the combinations N_3 P_2, N_3 P_1, N_2 P_1 and the lowest with N_2 P_3.

TABLE 82 : The Influence of NK Interaction on 100 Seed Weight

Nutrient	Means of 30 Plants (g)		
	K_1	K_2	K_3
N_1	41.72 f	46.92 ab	47.18 ab
N_2	45.46 cd	45.00 de	44.26 e
N_3	46.26 bc	47.32 a	46.55 ab

5% LSD = 0.957

Data followed by different letters (a-f) are significantly different.

From this table it can be seen that the highest 100 seed weight was obtained with the combinations N_3 K_2, N_1 K_3, N_1 K_2, N_3 K_3 and the lowest with N_1 K_1.

TABLE 83 : The Influence of PK Interaction on 100 Seed Weight

Nutrient	Means of 10 Plants (g)		
	K_1	K_2	K_3
P_1	48.30 a	45.86 bc	45.16 c
P_2	44.19 d	46.64 b	46.80 b
P_3	40.93 e	46.75 b	46.03 bc

5% LSD = 0.957

Data followed by different letters (a-e) are significantly different.

The highest 100 seed weight was obtained with the combination P_1 K_1 followed by the P_2 K_3, P_3 K_2; P_2 K_2, P_3 K_3, P_1 K_2 and the lowest with the P_3K_1.

TABLE 84 : The Influence of N P K Interaction on 100 Seed Weight

Nutrient	Means of 10 Plants (g)		
	K_1	K_2	K_3
P_1	45.81 fgh	43.06 jk	46.73 defg
N_1 P_2	40.67 m	48.58 bc	47.20 cdef
P_3	38.67 n	49.11 b	47.60 bcde
P_1	50.99 a	47.02 cdef	42.41 kl
N_2 P_2	44.48 hij	44.18 hij	45.16 ghi
P_3	40.90 lm	43.80 ijk	45.19 ghi
P_1	48.11 bcd	47.49 bcde	46.32 efg
N_3 P_2	47.43 cdef	47.16 cdef	48.02 bcd
P_3	42.23 jk	47.33 cdef	45.30 ghi

5% LSD = 1.657

Data followed by different letters (a-n) are significantly different.

It can be seen from this Table that the highest 100 seed weight was obtained with the combination N_2 P_1 K_1 followed by the N_1 P_3 K_2, N_1 P_2 K_2, N_3 P_1 K_1, N_3 P_2 K_3, and lighter seed weight with the combinations N_1 P_3 K_1, N_1 P_2 K_1, N_2 P_3 K_1, N_2 P_1 K_3.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that of the nutrients examined only phosphorus had a main effect and from their interactions only the NP significantly affected the germination percentage at 1% level.

The germination percentages due to the main effects of N, P and K and due to the NP interaction are given in Tables 85 and 86.

TABLE 85 : The Influence of N, P and K (Main effects) on Germination Percentage

Nutr. Level	Means of 45 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	75.07 a	93.36	81.01 a	97.56	71.61 a	90.05
2nd	73.32 a	91.76	71.92 b	90.37	73.16 a	91.61
3rd	73.06 a	91.51	68.52 b	86.59	76.67 a	94.68

5% LSD = 4.75 (for angles) | 4.75 | 4.75

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the 1st level of phosphorus significantly increased the percentage germination compared with the 2nd and 3rd levels which gave similar results.

TABLE 86 : The Influence of NP Interaction on Mean Germination Percentage

Nutr.	Means of 15 Plants					
	P_1		P_2		P_3	
	Angles	%	Angles	%	Angles	%
N_1	74.93 bcd	93.24	75.78 bc	93.80	74.69 bcd	93.03
N_2	86.13 a	99.54	70.09 cde	88.40	63.73 e	80.41
N_3	81.97 ab	98.05	70.09 cde	88.40	67.12 de	84.88

5% LSD = 8.22 (for angles)
Data followed by different letters (a-e) are significantly different.

The highest germination percentages were obtained with the N_2P_1 and N_3 P_1 and the lowest ones with N_2 P_3 and N_3 P_3.

(b) Germination Rate

From the analysis of variance it was found that all the nutrients had a significant effect on germination rates, nitrogen and phosphorus at 1% level and potassium at 5% level. From the interactions only the PK interaction was found to have a significant effect at 5% level.

The germination rate due to the main effects of N,P and K and due to the interaction PK are given in Tables 87 and 88.

TABLE 87 : The Influence of N, P and K (Main effects) on Germination Rate

Nutrient Levels	Means of 45 Plants		
	N	P	K
1st	14.14 a	14.15 a	13.90 b
2nd	14.03 a	13.79 b	13.87 b
3rd	13.76 b	13.99 ab	14.17 a
5% LSD	0.23	0.23	0.23

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that in the case of nitrogen the best germination rate was achieved with the 1st and 2nd levels, in the case of phosphorus with the 1st level and in the case of potassium with the 3rd level.

($\underline{N_1, N_2}$, N_3), ($\underline{P_1, P_3, P_2}$), ($K_3$, $\underline{K_1, K_2}$).

TABLE 88 : The Influence of PK Interaction on Germination Rate

Nutrient	Means of 15 Plants		
	K_1	K_2	K_3
P_1	13.90 bc	14.11 ab	14.44 a
P_2	13.63 c	13.85 bc	13.88 bc
P_3	14.16 ab	13.63 c	14.17 ab

5% LSD = 0.400

Data followed by different letters (a,b,c) are significantly different.

It can be observed that the best germination rate was achieved with the combinations P_1 K_3, P_3 K_3, P_3 K_1, P_1 K_2.

(c) Seedling Dry Weight

From the analysis of variance it was found that all the nutrients and all their interactions had a highly significant effect the 1% level on seedling dry weight.

The seedling dry weights due to the N, P, K and their interactions are given in Tables 89, 90, 91, 92 and 93.

TABLE 89 : The Influence of N, P and K (Main effects) on Seedling Dry Weight

Nutrient Level	Means of 45 Plants (g)		
	N	P	K
1st	0.118 b	0.126 a	0.108 c
2nd	0.116 b	0.116 b	0.119 b
3rd	0.122 a	0.113 b	0.127 a

5% LSD = 0.003

Data followed by different letters (a,b,c) within a column are significantly different.

Therefore in the case of nitrogen the 3rd level gave the heaviest seedlings followed by the 1st and 2nd levels, and in the case of phosphorus the 1st level gave the heaviest followed by the 2nd and 3rd levels and in the case of potassium the seedling dry weight increased with the nutrient increase (N_3, $\underline{N_1, N_2}$); (P_1, $\underline{P_2, P_3}$), ($K_3 > K_2 > K_1$).

TABLE 90 : The Influence of NP Interaction on Seedling Dry Weight

Nutrient	Means of 15 Plants (g)		
	P_1	P_2	P_3
N_1	0.112 c	0.121 b	0.120 b
N_2	0.131 a	0.108 c	0.108 c
N_3	0.136 a	0.120 b	0.110 c

5% LSD = 0.006

Data followed by different letters (a,b,c) are significantly different.

It can therefore be seen that the heaviest seedlings were produced with the N_3 P_1 and N_2 P_1 combinations and the lightest with the N_2 P_2, N_2 P_3, N_3 P_3, N_1 P_1, combinations.

TABLE 91 : The Influence of NK Interaction on Seedling Dry Weight

Nutrient	Means of 15 Plants (g)		
	K_1	K_2	K_3
N_1	0.103 e	0.120 c	0.130 ab
N_2	0.113 d	0.113 d	0.121 c
N_3	0.109 d	0.125 bc	0.132 a

5% LSD = 0.006

Data followed by different letters (a-e) are significantly different.

Therefore the heaviest seedlings were produced with the N_3 K_3 and N_1 K_3 combinations and the lightest with the N_1 K_1, N_3 K_1 combinations.

TABLE 92 : The Influence of PK Interaction on Seedling Dry Weight

Nutrient	Means of 15 Plants (g)		
	K_1	K_2	K_3
P_1	0.120 c	0.130 a	0.129 ab
P_2	0.100 e	0.119 c	0.130 a
P_3	0.105 de	0.109 d	0.124 bc

5% LSD = 0.006

Data followed by different letters (a-e) are significantly different.

Therefore the heaviest seedlings were produced with the P_2 K_3, P_1 K_2, P_1 K_3 combinations and the lightest with the P_2 K_1 and P_3 K_1.

TABLE 93 : The Influence of NPK Interaction on Seedling Dry Weight

Nutrient	Means of 5 Plants (g)		
	K_1	K_2	K_3
P_1	0.106 hijk	0.109 ghij	0.122 def
N_1 P_2	0.098 kl	0.132 abcd	0.133 abc
P_3	0.105 hijk	0.120 ef	0.135 abc
P_1	0.128 bcde	0.139 a	0.125 cde
N_2 P_2	0.098 kl	0.106 hijk	0.121 ef
P_3	0.112 fghi	0.094 l	0.118 efg
P_1	0.126 cde	0.142 a	0.140 a
N_3 P_2	0.102 ijkl	0.121 ef	0.137 ab
P_3	0.099 jkl	0.113 fgh	0.118 efg

5% LSD = 0.011

Data followed by different letters (a-l) are significantly different.

The heaviest seedlings were produced with the N_3 P_1 K_2, N_3 P_1 K_3, N_2 P_1 K_2 N_3 P_2 K_3, N_1 P_3 K_3 and N_1 P_2 K_3 treatments while the lightest with the N_2 P_3 K_2, N_1 P_2 K_1, N_2 P_2 K_1, N_3 P_3 K_1 and N_3 P_2 K_1 treatments.

Seedling Evaluation Test

(a) Emergence Percentage

The emergence percentages after their transformation in angles, were statistically analysed. From the analysis of variance it was found that there was a significant effect from phosphorus at the 1% level, because of NP interaction at the 5% level and because of PK interaction at 1% level.

Tables 94, 95 and 96 show the emergence percentages due to N, P, K main effects and NP, PK interactions.

TABLE 94: The Influence of N, P and K (Main effects) on Emergence Percentage

Nutr. Level	Means of 36 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	83.7 a	98.81	86.3 a	99.59	81.8 a	97.98
2nd	80.3 a	97.18	79.7 b	96.79	81.7 a	97.92
3rd	81.0 a	97.56	79.1 b	96.42	81.6 a	97.85
5% LSD =	3.3		3.3		3.3	

Data followed by different letters (a, b) within a column are significantly different.

Therefore the 1st level of phosphorus gave better emergence percentage

TABLE 95: The Influence of NP Interaction on Emergence Percentage

Nutr.	Means of 12 plants					
	P_1		P_2		P_3	
	Angles	%	Angles	%	Angles	%
N_1	84.2 ab	98.99	84.7 ab	99.16	82.3 bc	98.19
N_2	86.7 ab	99.67	77.6 c	95.37	76.8 c	94.75
N_3	88.1 a	99.89	76.7 c	94.73	78.3 c	95.86

5% LSD = 5.77 (for angles)

Data followed by different letters (a-d) are significantly different.

It can be observed that the highest emergence percentages were achieved with the combinations N_3 P_1, N_2 P_1, N_1 P_2, N_1 P_1, and N_1 P_3.

TABLE 96: The Influence of PK Interaction on Emergence Percentage

Nutr.	Means of 12 Plants					
	K_1		K_2		K_3	
	Angles	%	Angles	%	Angles	%
P_1	87.1 ab	99.75	88.1 a	99.89	83.8 ab	98.84
P_2	74.1 d	92.48	82.0 bc	98.06	82.9 abc	98.50
P_3	84.3 ab	99.02	75.0 d	93.32	77.9 cd	95.63

5% LSD = 5.77 (for angles)

Date followed by different letters (a-d) are significantly different.

It can be observed that the highest emergence percentages were achieved with the combinations P_1 K_2, P_1 K_1, P_3 K_3.

(b) Emergence Rate

None of the nutrients examined or their interactions had a significant effect on emergence rate.

The values of the emergence rate due to the main effects of N, P and K are given in Table 97.

TABLE 97 : The Influence of N, P and K on Emergence Rate

Nutrient Level	Means of 36 Plants		
	N	P	K
1st	11.56	11.58	11.58
2nd	11.74	11.48	11.58
3rd	11.46	11.70	11.60

5% LSD = 0.25

(c) Seedling Dry Weight

From the analysis of variance it was found that all the nutrients N, P and K had a significant effect on seedling dry weight at the 1% level and from their interactions the NP had a significant effect at the 1% level and the NK at 5% level.

Tables 98,99 and 100 give the seedling dry weights due to the N, P and K main effects and the NP and N K interactions.

TABLE 98 : The Influence of N, P and K (Main effects) on Seedling Dry Weight

Nutrient Levels	Means of 36 Plants (g)		
	N	P	K
1st	0.328 b	0.360 a	0.315 b
2nd	0.319 b	0.321 b	0.327 b
3rd	0.348 a	0.313 b	0.351 a

5% LSD = 0.016

Data followed by different letters (a,b) within a column are significantly different.

Therefore it can be observed that in the case of nitrogen the heaviest seedling was produced with the 3rd level (N_3, N_1, N_2), in the case of phosphorus the heaviest seedling was produced with the 1st level (P_1, P_2, P_3) and in the case of potassium with the 3rd level (K_3, K_2, K_1).

TABLE 99 : The Influence of NP Interaction on Seedling Dry Weight

Nutrient	Means of 12 Plants (g)		
	P_1	P_2	P_3
N_1	0.317 bc	0.339 b	0.326 b
N_2	0.370 a	0.289 d	0.297 cd
N_3	0.393 a	0.335 b	0.316 bcd

5% LSD = 0.028

Data followed by different letters (a-d) are significantly different.

Therefore the heaviest seedlings were produced by the N_3 P_1, and N_2 P_1 combinations, followed by the N_1 P_2, N_3 P_2, N_1 P_3. The lightest seedlings were produced by the N_2 P_2 and the N_2 P_3 combinations.

TABLE 100 : The Influence of NK Interaction on Seedling Dry Weight

Nutrient Level	Means of 12 Plants (g)		
	K_1	K_2	K_3
N_1	0.293 e	0.333 bcd	0.357 ab
N_2	0.321 cd	0.311 de	0.325 cd
N_3	0.332 bcd	0.339 bc	0.373 a

5% LSD = 0.028

Data followed by different letters (a-e) are significantly different.

Therefore the heaviest seedlings were produced by the N_3 K_3 and N_1 K_3 combinations and the lightest by the N_1 K_1, N_2 K_2, N_2 K_1, N_2 K_3 combinations.

(d) Percentage of Very Weak Seedlings

From the analysis of variance it was found that the percentage of very weak seedlings were significantly affected by phosphorus and potassium levels and by the NP interaction at 1% level.

Tables 101 and 102 give these percentages due to the N,P and K main effects and the NP interaction.

TABLE 101 : The Influence of N, P and K (Main effects) on Percentage of Very Weak Seedlings

Nutr. Level	Means of 36 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	13.21 a	5.22	8.17 c	2.02	15.28 a	6.94
2nd	15.18 a	6.86	15.38 b	7.03	17.57 a	9.11
3rd	14.22 a	6.03	19.06 a	10.66	9.76 b	2.87

5% LSD = 3.26 (for angles)

Data followed by different letters (a,b,c) within a column are significantly different.

It can be observed that in the case of phosphorus most of the weak seedlings were produced with the 3rd level, followed respectively by the 2nd and 1st levels. (P_3 > P_2 > P_1), and in the case of potassium most of the weak seedling were produced with the 2nd and 1st levels (K_2, K_1, K_3).

TABLE 102 : The Influence of NP Interaction on Percentage of Very Weak Seedlings

Nutr.	Means of 12 Plants					
	P_1		P_2		P_3	
	Angles	%	Angles	%	Angles	%
N_1	12.23 bc	4.49	11.62 bc	4.06	15.78 ab	7.39
N_2	5.65 d	0.97	18.50 a	10.07	21.40 a	13.31
N_3	6.63 cd	1.33	16.02 ab	7.62	20.01 a	11.71

5% LSD = 5.65 (for angles)

Data followed by different letters (a-d) are significantly different.

It can be observed that the highest percentages of very weak seedlings were produced with the $N_2 P_3$, $N_3 P_3$, $N_2 P_2$ combinations and the smallest with the $N_2 P_1$, $N_3 P_1$, $N_1 P_1$ combinations.

(e) Percentage of Weak Seedlings

From the analysis of variance it was found that these percentages were significantly affected only by phosphorus and potassium at 5% level and 1% levels of significance respectively.

These percentages due to the N, P and K main effects are presented in Table 103.

TABLE 103 : The Influence of N, P and K (Main effects) on Percentage of Weak Seedlings

Nutrient Levels	Means of 36 Plants		
	N	P	K
1st	37.43 a	34.48 b	45.52 a
2nd	40.23 a	39.85 a	35.85 b
3rd	36.17 a	39.20 a	35.46 b

5% LSD = 3.94

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the highest percentage of weak seedlings were produced with the 2nd and 3rd levels of phosphorus and the 1st level of potassium $(\underline{P_2, P_3}, P_1)$, $(K_1, \underline{K_2, K_3})$.

(f) Percentage of Vigorous Seedlings

From the analysis of variance it was found that these percentages were significantly affected by nitrogen at 5% level and by phosphorus, potassium and NP interaction at 1% level. Tables 104 and 105 present the percentages of vigorous seedlings due to N,P and K main effects and due to NP interaction.

TABLE 104 : The Influence of N, P and K (Main effects) on Percentage of Vigorous Seedlings

Nutrient levels	Means of 36 Plants		
	N	P	K
1st	55.69 a	61.61 a	48.91 b
2nd	50.45 b	51.17 b	52.74 b
3rd	55.30 a	48.65 b	59.79 a

5% LSD = 4.15

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the highest percentages of vigorous seedlings were produced with nitrogen by the 1st and 3rd levels ($\underline{N_1, N_3}$, N_2), with phosphorus by the 1st level (P_1, $\underline{P_2, P_3}$), and with potassium by the 3rd level (K_3, $\underline{K_2, K_1}$).

TABLE 105 : The Influence of NP Interaction on Percentage of Vigorous Seedlings

Nutrient	Means of 12 Plants		
	P_1	P_2	P_3
N_1	56.82 bc	56.31 bc	53.93 cd
N_2	62.25 ab	44.09 e	45.00 e
N_3	65.76 a	53.12 cd	47.03 de

5% LSD = 7.18

Data followed by different letters (a,b,c,d,e) are significantly different.

It can be observed that the highest percentages of vigorous seedlings were produced with the N_3 P_1, N_2 P_1, N_1 P_1, N_1 P_2 combinations and the lowest ones with the N_2 P_2, N_2 P_3, N_3 P_3 combinations.

Cold Test

(a) Percentage of Emergence

From the analysis of variance it was found that the percentage of emergence in the cold test was significantly affected by the nitrogen and phosphorus at 1% level, by potassium at 5% level, by the NP interaction at 1% and the by the NPK interaction at 5% level.

Tables 106, 107 and 108 present these percentages due to N,P,K main effects and due to NP and NPK interactions.

TABLE 106 : The Influence of N, P and K (Main effects) on Percentage of Emergence in the Cold Test

Nutr. Level	Means of 36 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	6.19 b	1.16	13.68 a	5.59	8.03 b	1.95
2nd	7.24 b	1.59	5.75 b	1.00	7.37 b	1.64
3rd	13.68 a	5.59	7.67 b	1.78	11.70 a	4.11

5% LSD = 3.24 (for the angles)

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the highest emergence percentages were achieved in the case of nitrogen with the 3rd level (N_3 $\underline{N_2\ N_1}$), in the case of phosphorus with the 1st level (P_1 $\underline{P_3\ P_2}$) and the in the case of potassium with the 3rd level (K_3 $\underline{K_2\ K_1}$).

TABLE 107 : The Influence of NP Interaction on Percentage of Emergence in the Cold Test

Nutr.	Means of 12 Plants					
	P_1		P_2		P_3	
	Angles	%	Angles	%	Angles	%
N_1	6.35cde	1.22	2.88e	0.25	9.32bcd	2.62
N_2	13.21 b	5.22	4.66cde	0.66	3.85 de	0.45
N_3	21.49 a	13.42	9.71bc	2.84	9.85 bc	2.93

5% LSD (for the angles) = 5.61

Data followed by different letters (a-e) are significantly different.

It can be observed that the highest percentages were achieved with the combinations N_3P_1 and N_2P_1 and the lowest ones with N_1P_2, N_2P_3, N_2P_2.

TABLE 108 : The Influence of NPK Interaction on Percentage of Emergence in the Cold Test

Nutr.		Means of 4 Plants					
		K_1		K_2		K_3	
		Angles	%	Angles	%	Angles	%
	P_1	0.00	0.00	5.77	1.01	13.68	5.28
N_1	P_2	2.88	0.25	2.88	0.25	2.89	0.25
	P_3	15.21	6.88	5.77	1.01	6.99	1.48
	P_1	5.77	1.01	20.22	11.94	13.63	5.55
N_2	P_2	4.11	0.51	4.11	0.51	5.77	1.01
	P_3	5.77	1.01	0.00	0.00	5.77	1.01
	P_1	24.93	17.77	15.21	6.88	24.32	16.96
N_3	P_2	2.89	0.25	9.52	2.73	16.73	8.29
	P_3	10.75	3.48	2.89	0.25	15.90	7.50

5% LSD (for the angles) = 9.72

It can be observed from Table 108 that the highest percentages of emergence in the cold test were achieved with the treatments $N_3\ P_1\ K_1$, $N_3\ P_1\ K_3$, $N_2\ P_1\ K_2$, $N_3\ P_2\ K_3$, $N_3\ P_3\ K_3$ and the lowest with the treatments $N_1\ P_1\ K_1$, $N_2\ P_3\ K_2$, $N_1\ P_2\ K_1$, $N_1\ P_2\ K_2$, $N_1\ P_2\ K_3$, $N_3\ P_2\ K_1$, $N_3\ P_3\ K_2$.

(b) Percentage of Mortality

From the analysis of variance it was found that the percentage of mortality in the cold test was significantly affected by the nitrogen and phosphorus at 1% level and by potassium and NP interaction at 5% level.

Tables 109 and 110 present these percentages due to N, P and K main effects and due to NP interaction.

TABLE 109: The Influence of N, P and K (Main effects) on Percentage of Mortality in the Cold Test

Nutr. Level	Means of 36 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	83.4 a	98.66	76.0 b	94.15	81.5 ab	97.82
2nd	82.8 a	98.41	84.1 a	98.95	82.6 a	98.35
3rd	76.3 b	94.41	82.3 a	98.22	78.3 b	95.89

5% LSD (for the angles) = 3.33

Data followed by different letters (a,b) within a column are significantly different

It can be observed from Table 109 that the highest mortality was observed in the case of nitrogen with 1st and 2nd levels ($\underline{N_1\ N_2}\ N_3$), in the case of phosphorus with the 2nd and 3rd levels ($\underline{P_2\ P_3}\ P_1$), and in the case of potassium with the 2nd and 1st levels ($\underline{K_2\ K_1}\ K_3$).

TABLE 110: The Influence of NP Interaction on Percentage of Mortality in the Cold Test

Nutr.	Means of 12 Plants					
	P_1		P_2		P_3	
	Angles	%	Angles	%	Angles	%
N_1	82.7 abc	98.38	86.7 a	99.67	80.7 bcd	97.38
N_2	76.8 d	94.78	85.3 abc	99.34	86.1 a	99.55
N_3	68.5 e	86.58	80.3 cd	97.15	80.2 cd	97.07

5% LSD (for the angles)= 5.76

Data followed by different letters (a,b,c) are significantly different

It can be observed that the highest mortality occurred with the combinations $N_1\ P_2$, $N_2\ P_3$, $N_2\ P_2$ and the lowest with the combination $N_3\ P_1$, followed in order by $N_2\ P_1$, $N_1\ P_3$, $N_3\ P_3$, $N_3\ P_2$.

Electrical Conductivity

From the analysis of variance it was found that the electrical conductivity of the leakage of the soaked seeds, measured in micro-siemens per g (μS/g) was significantly affected by nitrogen, phosphorus, potassium and NK interaction at 1% level.

In Tables 111 and 112 the values are given of the electrical conductivity due to the N, P and K main effects and due to the NK interaction.

TABLE 111 : The Influence of N, P and K (Main effects) on Electrical Conductivity

Nutrient Levels	Means of 24 Plants (in μS/g)		Means of 36 Plants (in μS/g)
	N	K	P
1st	60.20 a	59.45 a	-
2nd	58.13 b	56.97 b	56.57 b
3rd	54.85 c	56.76 b	58.89 a
5% LSD	1.02	1.02	0.83

Data followed by different letters (a,b,c) within a column are significantly different.

It can be observed from Table 111 that the highest electrical conductivity was achieved in the case of nitrogen with the 1st level followed by the 2nd and 3rd respectively, in the case of phosphorus with the 3rd level and in the case of potassium with the 1st level ($N_1 > N_2 > N_3$), ($P_3 > P_2$), (K_1 $\underline{K_2\ K_3}$).

TABLE 112 : The Influence of NK Interaction on Electrical Conductivity

Nutrient	Means of 8 Plants (in µS/g)		
	K_1	K_2	K_3
N_1	65.30 a	57.54 bc	57.75 bc
N_2	58.07 bc	59.27 b	57.06 cd
N_3	54.99 e	54.09 e	55.48 de

5% LSD = 1.77

Data followed by different letters (a-e) are significantly different.

It is therefore evident that the highest electrical conductivity was achieved with the combiations N_1 K_1, N_2 K_2, N_2 K_1, and the lowest with the N_3 K_2, N_3 K_1, N_3 K_3 combinations.

Total Nitrogen Content

After the analysis of variance it was found that the total nitrogen content of the seed was affected by the nitrogen and phosphorus fertilizers at 1% level, by the NP interaction at the 5% level and by the NK and NPK interactions at 1% level.

Tables 113, 114, 115 and 116 show the seed total nitrogen content in percentage of dry matter, due to N, P, K main effects and due to NP, NK and NPK interactions.

TABLE 113 : The Influence of N, P and K (Main effects) on Seed Nitrogen Content

Nutrient Levels	Means of 27 Plants		
	N	P	K
1st	3.421 b	3.849 a	3.593 a
2nd	3.512 b	3.393 b	3.501 a
3rd	3.713 a	3.404 b	3.553 a

5% LSD = 0.123

Data followed by different letters (a,b) within a column are significantly different.

It can therefore be observed that the highest seed nitrogen content was obtained with the 3rd level of nitrogen and in the case of phosphorus with the 1st level.

TABLE 114 : The Influence of NP Interaction on Seed Nitrogen Content

Nutrient	Means of 9 Plants		
	P_1	P_2	P_3
N_1	3.784 abc	3.178 f	3.300 ef
N_2	3.867 ab	3.424 de	3.244 ef
N_3	3.896 a	3.576 cd	3.669 bc

5% LSD = 0.213

Data followed by different letters (a-f) are significantly different.

It can be observed that the highest seed nitrogen content was achieved with the combinations N_3 P_1, N_2 P_1, N_1 P_1, N_3 P_3 and the lowest with the N_1 P_2, N_2 P_3, N_1 P_3.

TABLE 115 : The Influence of NK Interaction on Seed Nitrogen Content

Nutrient	Means of 9 Plants		
	K_1	K_2	K_3
N_1	3.242 e	3.476 bc	3.544 bc
N_2	3.627 b	3.384 cd	3.524 bc
N_3	3.909 a	3.642 b	3.589 bc

5% LSD = 0.213

Data followed by different letters (a-e) are significantly different.

It can therefore be observed that the highest seed nitrogen content was achieved with the combinations N_3 K_1, N_3 K_2, N_2 K_1, N_3 K_3 and the lowest with N_1 K_1, N_2 K_2, N_1 K_2 and N_2 K_3.

TABLE 116 : The Influence of NPK Interaction on Seed Nitrogen Content

Nutrient	Means of 3 Plants		
	K_1	K_2	K_3
N_1 P_1	3.853 abc	3.680 bcdefg	3.820 abcde
N_1 P_2	2.867 k	3.280 hij	3.387 ghi
N_1 P_3	3.007 jk	3.467 efghi	3.427 fghi
N_2 P_1	4.107 a	3.853 abc	3.640 bdefgh
N_2 P_2	3.407 fghi	3.413 fghi	3.453 efghi
N_2 P_3	3.367 ghij	2.887 k	3.480 defghi
N_3 P_1	3.847 abcd	3.933 ab	3.907 abc
N_3 P_2	3.953 ab	3.227 ijk	3.547 cdefghi
N_3 P_3	3.927 ab	3.767 abcdef	3.313 ghij

5% LSD = 0.369

Data followed by different letters (a-k) are significantly different.

It can therefore be observed that the highest seed nitrogen content was achieved with the combinations N_2 P_1 K_1, N_3 P_2 K_1, N_3 P_1 K_2, N_3 P_3 K_1, N_3 P_1 K_3 and the lowest with N_1 P_2 K_1, N_2 P_3 K_2, N_1 P_3 K_1, N_3 P_2 K_2, N_1 P_2 K_2, N_3 P_3 K_3, and N_2 P_3 K_1.

Seed Phosphorus Content

From the analysis of variance it was found that the phosphorus content of the seed was affected by the phosphorus fertilizers at 1% level, by potassium fertilizers at 1% level and by the NPK interaction at 5% level.

Tables 117 and 118 give the percentages of phosphorus content of the seed due to N, P and K main effects and due to NPK interactions.

TABLE 117 : The Influence of N, P and K (Main effects) on Seed Phosphorus Content

Nutrient Levels	Means of 27 Plants		
	N	P	K
1st	0.386 a	0.345 b	0.426 a
2nd	0.387 a	0.388 ab	0.371 b
3rd	0.372 a	0.412 a	0.348 b

5% LSD = 0.044

Data followed by different letters (a,b) within a column are significantly different.

It can therefore be observed that the highest phosphorus content in the seeds was obtained with the 3rd level of phosphorus and by the 1st level of potassium.

TABLE 118 : The Influence of NPK Interaction on Seed Phosphorus Content

Nutrient	Means of 3 Plants		
	K_1	K_2	K_3
N_1 P_1	0.337	0.371	0.353
N_1 P_2	0.384	0.451	0.324
N_1 P_3	0.437	0.377	0.440
N_2 P_1	0.417	0.313	0.363
N_2 P_2	0.431	0.429	0.315
N_2 P_3	0.508	0.287	0.424
N_3 P_1	0.369	0.349	0.232
N_3 P_2	0.504	0.305	0.349
N_3 P_3	0.443	0.459	0.336

5% LSD = 0.131

It can therefore be observed that the highest phosphorus content in the seeds was obtained by the combinations N_2 P_3 K_1, N_3 P_2 K_1, N_3 P_3 K_2, N_1 P_2 K_2, N_3 P_3 K_1, N_1 P_3 K_3, N_1 P_3 K_1, N_2 P_2 K_1, N_2 P_2 K_2, N_2 P_3 K_3, N_2 P_1 K_1 and the lowest by N_3 P_1 K_3, N_2 P_3 K_2, N_3 P_2 K_2, N_2 P_1 K_2, N_2 P_2 K_3, N_1 P_2 K_3, N_3 P_3 K_3, N_1 P_1 K_1, N_3 P_1 K_2 and N_3 P_2 K_3.

Seed Potassium Content

From the analysis of variance it was found that the potassium content of the seed was affected by the nitrogen and potassium fertilizers at 1% level and by the NP interaction at 5% level.

Tables 119 and 120 give the percentages of potassium content in the seeds due to N, P and K main effects and due to NP interaction.

TABLE 119 : The Influence of N,P and K (Main effects) on Seed Potassium Content

Nutrient Levels	Means of 27 Plants		
	N	P	K
1st	0.910 a	0.849 a	0.738 c
2nd	0.790 b	0.837 a	0.843 b
3rd	0.790 b	0.803 a	0.908 a

5% LSD = 0.055

Data followed by different letters (a,b,c) within a column are significantly different.

It can be observed that the highest potassium content in the seeds was obtained by the 1st level of nitrogen and the 3rd level of potassium (N_1 $\underline{N_2\ N_3}$), ($K_3 > K_2 > K_1$).

TABLE 120 : The Influence of NP Interaction on Seed Potassium Content

Nutrient	Means of 3 Plants		
	P_1	P_2	P_3
N_1	0.929 a	0.880 abc	0.920 ab
N_2	0.796 cd	0.876 abc	0.698 e
N_3	0.822 cd	0.756 de	0.791 cde

5% LSD = 0.095

Data followed by different letters (a-e) are significantly different.

Therefore the highest potassium content in the seed was obtained with the combinations N_1 P_1, N_1 P_3, N_1 P_2, N_2 P_2, the lowest with N_2 P_3, N_3 P_2, N_3 P_3 and N_2 P_1.

Experiment No. 3

Plant Growth

The plant growth, measured as stem dry matter (without leaves), was found to be significantly affected by nitrogen only at 1% level of significance.

Table 121 gives the stem dry matter (in g.) as affected by N and Mo levels.

TABLE 121 : The Influence of N and Mo (Main effects) on Stem Dry Matter Weight

Nutrient Levels	Means of 24 Plants (g)	Means of 18 Plants (g)
	N	Mo
1st	3.51 b	4.38 a
2nd	4.97 a	4.71 a
3rd	5.07 a	4.64 a
4th	-	4.33 a
5% LSD	0.305	0.353

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that bigger plants were produced with the 3rd and 2nd levels of nitrogen (N_3, N_2, N_1).

Days to First Flower

From the analysis of variance it was found that the days from sowing to first flower were not significantly affected by the nitrogen and molybdenum levels or by their interaction.

Table 122 gives the days from sowing to the first flower due to the main effects of nitrogen and molybdenum.

TABLE 122 : The Influence of N and Mo (Main effects) on Mean Days to First Flower

Nutrient Levels	Means of 24 Plants (Days)	Means of 18 Plants (Days)
	N	Mo
1st	35.25	35.44
2nd	35.67	35.61
3rd	35.37	35.33
4th	-	35.33
5% LSD	0.44	0.51

Mean Days to Harvest

From the analysis of variance it was found that the number of days from sowing to harvest were not significantly affected by the nitrogen and molybdenum levels or by their interaction.

Table 123 gives the mean days to harvest due to the main effects of nitrogen and molybdenum.

TABLE 123 : The Influence of N and Mo (Main effects) on Mean Days to Harvest

Nutrient Levels	Means of 24 Plants (Days)	Means of 18 Plants (Days)
	N	Mo
1st	79.88	80.08
2nd	80.17	79.98
3rd	80.09	80.00
4th	-	80.11
5% LSD	0.33	0.38

Number of Pods Per Plant

It was found from the analysis of variance that the number of pods per plant were significantly affected by the nitrogen levels only, at 1% level of significance.

Table 124 gives the mean number of pods per plant as affected by nitrogen and molybdenum.

TABLE 124 : The Influence of N and Mo (Main effects) on Mean Number of Pods Per Plant

Nutrient Levels	Means of 24 Plants	Means of 18 Plants
	N	Mo
1st	13.21 c	15.61 a
2nd	17.08 b	17.11 a
3rd	18.71 a	16.33 a
4th	-	16.28 a
5% LSD	1.20	1.39

Data followed by different letters (a-c) within a column are significantly different.

More pods per plant were produced with the 3rd level of nitrogen followed by the 2nd and 1st levels respectively ($N_3 > N_2 > N_1$).

Number of Seeds Per Plant

Only the nitrogen levels significantly affected the number of seeds per plant at 1% level of significance.

Table 125 gives the mean number of seeds per plant due to N and Mo main effects.

TABLE 125 : The Influence of N and Mo (Main effects) on Mean Number of Seeds Per Plant

Nutrient Levels	Means of 24 Plants	Means of 18 Plants
	N	Mo
1st	62.5 c	72.7 a
2nd	78.2 b	77.8 a
3rd	85.8 a	76.1 a
4th	-	75.4 a
5% LSD	5.31	6.11

Data followed by different letters (a-c) within a column are significantly different.

It can be observed that more seeds were produced by the 3rd level of nitrogen followed by the 2nd and 1st levels ($N_3 > N_2 > N_1$).

Number of Seeds Per Pod

From the analysis of variance it was found that the number of seeds per pod were not significantly affected by nitrogen and molybdenum levels or by their interaction.

Table 126 gives the mean number of seeds per pod and per nutrient level, as they were affected by N and Mo.

TABLE 126 : The Influence of N and Mo (Main effects) on Mean Number of Seeds Per Pod

Nutrient Levels	Means of 24 Plants	Means of 18 Plants
	N	Mo
1st	4.75	4.70
2nd	4.61	4.56
3rd	4.61	4.70
4th	-	4.67
5% LSD	0.26	0.30

Seed Yield

From the analysis of variance it was found that the seed yield per plant was significantly affected by the nitrogen levels at 1% level of significance.

The values of seed yield per plant due to N and Mo are given in Table 127.

TABLE 127 : The Influence of N and Mo (Main effects) on Seed Yield Per Plant

Nutrient Levels	Means of 24 Plants (g)	Means of 18 Plants (g)
	N	Mo
1st	21.43 c	26.67 a
2nd	27.74 b	27.73 a
3rd	32.42 a	27.86 a
4th	-	26.51 a
5% LSD	1.84	2.12

Data followed by different letters (a-c) within a column are significantly different.

Therefore the highest seed yield was produced with the 3rd level of nitrogen followed respectively by the 2nd and 1st levels ($N_3 > N_2 > N_1$).

Seed to Empty Pod Ratio (S:EP)

From the analysis of variance it was found that the S:EP ratio was significantly affected by the nitrogen at 1% level.

Table 128 gives the S:EP values as they were affected by N and Mo.

TABLE 128 : The Influence of N and Mo (Main effects) on S:EP Ratio

Nutrient Levels	Means of 24 Plants	Means of 18 Plants
	N	Mo
1st	3.51 b	4.38 a
2nd	4.93 a	4.71 a
3rd	5.07 a	4.58 a
4th	-	4.34 a
5% LSD	0.31	0.35

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the best ratio occured with the 3rd and 2nd levels of nitrogen (N_3 $\underline{N_2}$ N_1).

Seed Size Determination

(a) Weight of Individual Seeds

From the analysis of variance it was found that the weight of individual seeds was significantly affected only by nitrogen at 1% level of significance.

Table 129 gives the seed weights due to the nitrogen and molybdenum main effects.

TABLE 129 : The Influence of N and Mo (Main effects) on Mean Seed Weight

Nutrient Levels	Means of 24 Plants (g)	Means of 18 Plants (g)
	N	Mo
1st	0.345 b	0.367 a
2nd	0.357 b	0.358 a
3rd	0.379 a	0.364 a
4th	-	0.352 a
5% LSD	0.015	0.017

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the heaviest seeds were produced with the 3rd level of nitrogen (N_3 $\underline{N_2\ N_1}$).

(b) 100 Seed Weight

From the analysis of variance it was found that the 100 seed weight was significantly affected by nitrogen, molybdenum and their interactions at 1% level. Tables 130 and 131 give the 100 seed weight due to N and Mo main effects and due to their interaction.

TABLE 130 : The Influence of N and Mo (Main effects) on 100 Seed Weight

Nutrient Levels	Means of 40 Plants (g)	Means of 30 Plants (g)
	N	Mo
1st	33.29 c	35.21 a
2nd	34.52 b	34.88 a
3rd	36.79 a	35.18 a
4th	-	34.21 b

5% LSD 0.55 0.64

Data followed by different letters (a-c) within a column are significantly different.

It can be observed that the heaviest seeds were produced with the 3rd level of nitrogen followed by the 2nd and 1st levels respectively and in the case of molybdenum with the 1st, 2nd and 3rd levels:

$(N_3 > N_2 > N_1)$, $(\underline{M_1\ M_3\ M_2}\ M_4)$.

TABLE 131 : The Influence of NM Interaction on 100 Seed Weight

Nutr.	Means of 10 Plants			
	M_1	M_2	M_3	M_4
N_1	33.90 de	34.12 cd	32.35 f	32.80 ef
N_2	35.02 c	32.91 ef	36.59 ab	33.55 de
N_3	36.69 ab	37.60 a	36.60 ab	36.29 b

5% LSD = 1.11

Data followed by different letters (a-f) are significantly different.

It can therefore be observed that the heaviest seeds were produced with the combinations $N_3\ M_2$; $N_3\ M_1$, $N_3\ M_3$, $N_2\ M_3$ and $N_3\ M_4$ and lighter seeds with $N_1\ M_3$, $N_1\ M_4$ and $N_2\ M_2$.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that only nitrogen had a significant effect on germination percentage at 5% level. The germination percentages due to the main effects of N and Mo are given in Table 132.

TABLE 132 : The Influence of N and Mo (Main effects) on Germination %

Nutr. Level	Means of 16 Plants		Means of 12 Plants	
	N		Mo	
	Angles	%	Angles	%
1st	80.8 b	97.44	84.6 a	99.11
2nd	89.7 a	99.99	85.3 a	99.33
3rd	89.7 a	99.99	88.3 a	99.91
4th	-	-	88.7 a	99.95
5% LSD (Angles)	7.69		8.87	

Data followed by different letters (a,b) within a column are significantly different.

It can be seen from Table 132 that the best germination occured with the 2nd and 3rd levels of nitrogen.

(b) Germination Rate

From the analysis of variance it was found that none of the nutrients or their interaction had a significant effect on germination rate. The values of germination rate due to the main effects of nitrogen and molybdenum are given in Table 133.

TABLE 133 : The Influence of N and Mo (Main effects) on Germination Rate

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	14.93	14.71
2nd	15.01	14.71
3rd	14.72	15.01
4th	-	15.12

5% LSD 0.39 0.45

(c) Seedling Dry Weight

From the analysis of variance it was found that only nitrogen had a significant effect on seedling dry weight at 1% level of significance. Table 134 gives the seedling dry weight due to the nitrogen and molybdenum main effects.

TABLE 134 : The Influence of N and Mo (Main effects) on Seedling Dry Wt.

Nutrient Level	Means of 16 Plants (g)	Means of 12 Plants (g)
	N	Mo
1st	0.114 b	0.117 a
2nd	0.116 b	0.118 a
3rd	0.121 a	0.118 a
4th	-	0.116 a

5% LSD 0.004 0.005

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the heaviest seedlings were produced with the 3rd level of nitrogen (N_3 $\underline{N_2\ N_1}$).

Seedling Evaluation Test

(a) Emergence Percentage

From the analysis of variance it was found that none of the nutrients examined had a significant effect on emergence percentage. Table 135 gives the emergence percentage due to the nitrogen and molybdenum main effects.

TABLE 135 : The Influence of N and Mo (Main effects) on Emergence %

Nutr. Level	Means of 16 Plants		Means of 12 Plants	
	N		Mo	
	Angles	%	Angles	%
1st	84.2	98.97	85.9	99.48
2nd	82.9	98.50	85.2	99.30
3rd	87.8	99.86	81.8	97.97
4th	-	-	87.1	99.75
5% LSD (Angles)	5.09		5.09	

(b) Emergence Rate

From the analysis of variance it was found that only nitrogen had a significant effect on emergence rate at 5% level. The values of emergence rate due to nitrogen and molybdenum main effects are given in Table 136.

TABLE 136 : The Influence of N and Mo (Main effects) on Emergence Rate

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	13.29 ab	13.41 a
2nd	13.55 a	13.28 a
3rd	12.95 b	13.19 a
4th	-	13.16 a
5% LSD	0.42	0.49

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the highest value of emergence rate was achieved with the 2nd level of nitrogen followed by the 1st level (N_2 $\underline{N_1\ N_3}$).

(c) Seedling Dry Weight

From the analysis of variance it was found that the seedling dry weight was significantly affected by the nitrogen and the nitrogen, molybdenum interaction at 5% and 1% levels respectively. Tables 137 and 138 give the dry seedling weights due to the main effects of N and Mo and due to their interaction.

TABLE 137 : The Influence of N and Mo (Main effects) on Seedling Dry Wt.

Nutrient Levels	Means of 16 Plants (g)	Means of 12 Plants (g)
	N	Mo
1st	0.316 b	0.333 a
2nd	0.343 ab	0.344 a
3rd	0.363 a	0.355 a
4th	-	0.331 a
5% LSD	0.034	0.039

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the heaviest seedlings in Table 137 were produced with the 3rd level of nitrogen followed by the 2nd level (N_3 N_2 N_1).

TABLE 138 : The Influence of N Mo Interaction on Seedling Dry Weight

Nutr.	Means of 4 Plants (g)			
	M_1	M_2	M_3	M_4
N_1	0.321 bcd	0.297 d	0.316 bcd	0.331 bcd
N_2	0.347 bcd	0.299 d	0.373 abc	0.354 bcd
N_3	0.331 bcd	0.434 a	0.377 ab	0.309 cd

5% LSD = 0.068

Data followed by different letters (a-d) are significantly different.

It can therefore be observed that the heaviest seedlings were produced with the treatment N_3 M_2 followed by the treatments N_3 M_3 and N_2 M_3. The lightest seedlings were produced with the treatments N_1 M_2, N_2 M_2, N_3 M_4 and N_1 M_3.

(d) Percentage of Very Weak Seedlings

These percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that none of the nutrients examined significantly affected the percentage of very weak seedlings.

Table 139 gives these percentages due to the N and Mo main effects.

TABLE 139 : The Influence of N and Mo (Main effects) on Percentage of Very Weak Seedlings

Nutr. Level	Means of 16 Plants		Means of 12 Plants	
	N		Mo	
	Angles	%	Angles	%
1st	18.0	9.55	19.0	10.60
2nd	20.0	11.70	18.6	10.17
3rd	15.9	7.50	16.7	8.26
4th	-	-	17.4	8.94
5% LSD (Angles)	5.46		6.31	

(e) Percentage of Weak Seedlings

From the analysis of variance it was found that none of the nutrients examined significantly affected the percentage of weak seedlings. Table 140 gives these percentages as affected by the N and Mo levels.

TABLE 140 : The Influence of N and Mo (Main effects) on Percentage of Weak Seedlings

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	50.1	46.6
2nd	45.2	44.4
3rd	46.9	46.2
4th	-	52.2
5% LSD	6.68	7.71

(f) Percentage of Vigorous Seedlings

From the analysis of variance it was found that only the interaction between nitrogen and molybdenum significantly affected the percentage of vigorous seedlings. Tables 141 and 142 give these percentages due to the N and Mo main effects and due to their interaction.

TABLE 141 : The Influence of N and Mo (Main effects) on Percentage of Vigorous Seedlings

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	38.7	41.7
2nd	42.8	43.3
3rd	44.3	44.2
4th	-	38.4
5% LSD	6.53	7.53

TABLE 142 : The Influence of N Mo Interaction on Percentage of Vigorous Seedlings

Nutr.	Means of 4 Plants			
	M_1	M_2	M_3	M_4
N_1	43.0 bc	34.7 c	37.4 bc	39.6 bc
N_2	44.1 abc	38.2 bc	48.0 ab	40.7 bc
N_3	38.0 bc	57.0 a	47.2 abc	35.0 bc

5% LSD : 13.05

Data followed by different letters (a-c) are signficantly different.

It can therefore be observed that the highest percentages of vigorous seedlings were achieved with the treatments $N_3 M_2$, $N_2 M_3$, $N_3 M_3$ and $N_2 M_1$.

Cold Test

(a) Emergence Percentage

From the analysis of variance it was found that the molybdenum and the interaction between nitrogen and molybdenum had a significant effect on emergence percentage at 5% and 1% levels respectively. These percentages due to N and Mo main effects and due to N Mo interaction are given in Tables 143 and 144.

TABLE 143 : The Influence of N and Mo (Main effects) on the Emergence Percentage in the Cold Test

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	31.9 a	26.7 b
2nd	31.5 a	38.1 a
3rd	32.5 a	28.0 b
4th	-	35.0 ab

5% LSD 7.31 8.43

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the percentage of emergence was higher with the M_2 and M_4 levels of molybdenum.

TABLE 144 : The Influence of N Mo Interaction on Percentage of Emergence in the Cold Test

Nutr.	Means of 4 Plants			
	M_1	M_2	M_3	M_4
N_1	17.1 c	34.4 ab	35.0 ab	41.1 a
N_2	30.0 abc	40.0 a	16.0 c	40.0 a
N_3	33.0 ab	40.0 a	33.0 ab	24.0 bc

5% LSD = 14.62

Data followed by different letters (a-c) are significantly different.

It can be seen that the lowest percentages of emergence occured with the treatments N_2 M_3, N_1 M_1, and N_3 M_4. All the other treatments resulted in percentages which do not differ significantly.

(b) Percentage of Mortality

From the analysis of variance it was found that the percentage of mortality in the cold test was significantly affected by the molybdenum levels and by the interaction between nitrogen and molybdenum both at 1% level of significance.

Tables 145 and 146 gives these percentages as affected by the N and Mo and their interaction.

TABLE 145 : The Influence of N and Mo (Main effects) on Percentage of Mortality in the Cold Test

Nutrient Level	Means of 16 Plants	Means of 12 Plants
	N	Mo
1st	65.6 a	72.8 a
2nd	67.0 a	57.0 c
3rd	67.2 a	70.7 ab
4th	-	63.4 bc
5% LSD	7.49	8.66

Data followed by different letters (a-c) within a column are significantly different.

It can therefore be seen that the highest mortality occured with the 1st and 3rd levels of molybdenum and the lowest with the 2nd and 4th levels.

TABLE 146 : The Influence of N Mo Interaction on Percentage of Mortality in the Cold Test

Nutr.	Means of 4 Plants			
	M_1	M_2	M_3	M_4
N_1	82.5 ab	59.9 cd	63.0 cd	57.2 d
N_2	69.0 bcd	56.0 d	84.0 a	59.0 d
N_3	67.0 cd	55.0 d	65.0 cd	74.0 abc

5% LSD = 14.99

Data followed by different letters (a-d) are significantly different.

It can therefore be observed that the highest mortality occured with the treatments $N_2 M_3$, $N_1 M_1$ and $N_3 M_4$. All the other treatments resulted in seeds with lower and not significantly different mortality.

Electrical Conductivity

From the analysis of variance it was found that the electrical conductivity of the leakage of the soaked seeds was significantly affected by the nitrogen and the interaction between nitrogen and molybdenum at 5% and 1% levels of significance respectively.

The values of the electrical conductivity in microsiemens per g., due to N and Mo and due to their interaction are given in Tables 147 and 148.

TABLE 147 : The Influence of N and Mo (Main effects) on the Electrical Conductivity

Nutrient Levels	Means of 16 Plants (μS/g)	Means of 12 Plants (μS/g)
	N	Mo
1st	66.66 a	66.96 a
2nd	64.96 b	65.36 a
3rd	67.25 a	66.48 a
4th	-	66.36 a
5% LSD	1.67	1.93

Data followed by different letters (a,b) within a column are significantly different.

It can be seen from Table 147 that the lower electrical conductivity was achieved with the 2nd level of nitrogen (N_3, N_1, N_2).

TABLE 148 : The Influence of N Mo Interaction on the Electrical Conductivity

Nutr	Means of 4 Plants (μS/g)			
	M_1	M_2	M_3	M_4
N_1	64.38 def	62.43 f	70.61 ab	69.21 abc
N_2	65.07 def	67.56 bcd	64.25 def	62.95 ef
N_3	71.43 a	66.08 cde	64.57 def	66.91 cd

5% LSD = 3.33

Data followed by different letters (a-f) are significantly different.

It can therefore be observed that the highest electroconductivity values were achieved with the treatments N_3 M_1, N_1 M_3 and N_1 M_4, while the lowest were achieved with the treatments N_1 M_2, N_2 M_4, N_2 M_3, N_1 M_1 and N_3 M_3.

Seed Total Nitrogen Content

From the analysis of variance it was found that the total nitrogen content in the seed was significantly affected by the nitrogen levels and by the nitrogen and molybdenum interaction at 1% level of significance.

Tables 149 and 150 give the percentages of total nitrogen content of seeds on a dry basis, due to N and Mo main effects and due to N Mo interaction.

TABLE 149 : The Influence of N and Mo (Main effects) on Seed Nitrogen Content

Nutrient Levels	Means of 12 Plants	Means of 9 Plants
	N	Mo
1st	2.222 b	2.472 a
2nd	2.319 b	2.393 a
3rd	2.637 a	2.316 a
4th	-	2.391 a
5% LSD	0.120	0.139

Data followed by different letters (a,b) within a column are significantly different.

It can be seen from Table 149 that the highest percentage of total nitrogen in the seed was achieved with the 3rd level of nitrogen (N_3, $\underline{N_2, N_1}$).

TABLE 150 : The Influence of N Mo Interaction on Seed Nitrogen Content

Nutr.	Means of 3 Plants			
	M_1	M_2	M_3	M_4
N_1	2.237 ef	2.537 abcd	1.887 g	2.130 fg
N_2	2.590 abc	2.167 fg	2.213 fg	2.307 def
N_3	2.590 abc	2.477 cde	2.747 a	2.737 ab

5% LSD = 0.241

Data followed by different letters (a-g) are signficantly different.

It can be seen that the highest percentage of total nitrogen content was achieved with the treatments N_3 M_3, N_3 M_4, N_3 M_1, N_2 M_1, and N_1 M_2 and the lowest with the treatments N_1 M_3, N_1 M_4, N_2 M_2 and N_2 M_3.

Seed Phosphorus Content

From the analysis of variance it was found that the seed phosphorus content was not affected by nitrogen and molybdenum or by their interaction.

Table 151 gives the content of seed phosphorus due to N and Mo main effects on a dry basis.

TABLE 151 : The Influence of N and Mo (Main effects) on Seed Phosphorus Content

Nutrient Levels	Means of 12 Plants	Means of 9 Plants
	N	Mo
1st	0.361	0.380
2nd	0.378	0.379
3rd	0.374	0.360
4th	-	0.365
5% LSD	0.031	0.036

Seed Potassium Content

From the analysis of variance it was found that the seed potassium content was significantly affected by nitrogen levels only at 1% level of significance.

Table 152 gives the potassium content of seeds on a dry basis due to N and Mo main effects as percentages.

TABLE 152 : The Influence of N and Mo (Main effects) on Potassium Content of Seeds

Nutrient Levels	Means of 12 Plants	Means of 9 Plants
	N	Mo
1st	0.947 b	1.027 a
2nd	1.100 a	1.107 a
3rd	1.147 a	1.071 a
4th	-	1.053 a
5% LSD	0.121	0.140

Data followed by different letters (a,b) within a column are significantly different.

It can be seen that the highest potassium content in the seed was achieved with the 3rd and 2nd levels of nitrogen ($\underline{N_3\ N_2}\ N_1$).

Experiment No. 4

Seed Yield

The seeds from the 50 plant per plot were weighed and the seed yield was expressed as the amount of seed per 50 plants. These figures were statistically analysed. From the analysis of variance it has been found that of the nutrients examined only nitrogen had a significant effect on seed yield at 1% level, and from the interactions only the NP at 5% level.

Tables 153 and 154 give the seed yield per 50 plants as they were affected by nitrogen and phosphorus and potassium and by the interaction between nitrogen and phosphorus.

TABLE 153 : The Influence of N, P and K (Main effects) on Mean Seed Yield per 50 Plants

Nutrient Levels	Means of 16 Plants (g)		
	N	P	K
1st	264.0 b	285.7 a	287.4 a
2nd	299.4 a	277.8 a	276.0 a
5% LSD	25.17	25.17	25.17

Data followed by different letters (a,b) within a column are signficantly different.

It can be seen from Table 153 that the 2nd level of nitrogen significantly increased the seed yield followed by the 1st level ($N_2 > N_1$).

Although the other nutrients did not change the seed yield significantly a slight decrease can be observed with the increase of phosphorus and potassium.

TABLE 154 : The Influence of NP Interaction on Mean Seed Yield Per 50 plants

Nutrient	Means of 8 Plants (g)	
	P_1	P_2
N_1	252.1 b	275.9 b
N_2	319.2 a	279.6 b

5% LSD = 35.59

Data followed by different letters (a,b) are significantly different.

On examining this interaction it can be seen that the combination N_2 P_1 gave the highest seed yield. All the other combinations gave similar seed yield but significantly lower than that of N_2 P_1.

100 Seed Weight

The analysis of variance showed that none of the nutrients examined or their interactions had a significant effect on the 100 seed weight.

Table 155 shows the 100 seed weights as affected by the nitrogen, phosphorus and potassium levels.

TABLE 155 : The Influence of N, P and K (Main effects) on 100 Seed Weight

Nutrient Levels	Means of 32 Plants (g)		
	N	P	K
1st	45.79	46.52	46.51
2nd	46.82	46.09	46.10
5% LSD	1.16	1.16	1.16

Although the nutrients examined did not change the 100 seed weight significantly a slight increase can be observed with the increase of nitrogen and a slight decrease with the increase of phosphorus and potassium.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that from the nutrients examined only potassium had a main effect at 1% level and from the interactions the NP and PK affected significantly the germination percentage at 5% level.

The germination percentages due to the main effects of N, P and K and due to their interactions NP and PK are given in Tables 156, 157 and 158.

TABLE 156 : The Influence of N, P and K (Main effects) on Germination Percentage

Nutrt. Level	Means of 32 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	71.41 a	89.84	74.36 a	92.73	70.09 b	88.40
2nd	73.83 a	92.24	70.89 a	89.28	75.16 a	93.44
5% LSD	3.63		3.63		3.63	

Data followed by different letters (a,b) within a column are significantly different.

It is therefore seen that the 2nd level of potassium significantly increased the percentage of germination compared with the 1st level.

TABLE 157 : The Influence of NP Interaction on Germination Percentage

Nutr.	Means of 16 Plants			
	P_1		P_2	
	Angles	%	Angles	%
N_1	70.92 b	89.31	71.90 b	90.35
N_2	77.79 a	95.53	69.87 b	88.16

5% LSD (Angles) = 5.13

Data followed by different letters (a,b) are significantly different.

It can therefore be observed that the germination percentage increased with the combination N_2 P_1. All other combinations gave significantly lower percentage of germination.

TABLE 158 : The Influence of PK Interaction on Germination Percentage

Nutr.	Means of 16 Plants			
	K_1		K_2	
	Angles	%	Angles	%
P_1	69.55 b	87.79	79.16 a	96.46
P_2	70.63 b	88.99	71.15 b	89.56

5% LSD (Angles) 5.13

Data followed by different letters (a,b) are significantly different.

It can therefore be seen that the highest germination percentage was achieved with the combination P_1 K_2 and the lowest with all the others which are not significantly different.

(b) Germination Rate

From the analysis of variance it was found that only nitrogen had a significant effect on germination rates at 5% level. The values of germination rates, as affected by nitrogen, phosphorus and potassium are given in Table 159.

TABLE 159 : The Influence of N,P & K (Main effects) on Germination Rate

Nutrient Levels	Means of 32 Plants		
	N	P	K
1st	13.790 a	13.721 a	13.698 a
2nd	13.613 b	13.682 a	13.705 a
5% LSD	0.139	0.139	0.139

Data followed by different letters (a,b) within a column are significantly different.

It can be observed that the best germination rate was achieved with the 1st level of nitrogen.

(c) Seedling Dry Weight

After the analysis of variance it was found that none of the nutrients examined had a significant effect on seedling dry weight. Table 160 gives the seedling dry weights due to the N, P and K main effects.

TABLE 160 : The Influence of N,P & K (Main effects) on Seedling Dry Wt.

Nutrient Levels	Means of 32 Plants (g)		
	N	P	K
1st	0.141	0.140	0.140
2nd	0.141	0.141	0.142
5% LSD	0.004	0.004	0.004

Seedling Evaluation Test

(a) Emergence Percentage

The emergence percentages, after their transformation into angles were statistically analysed. From the analysis of variance it was found that none of the nutrients examined had a significant effect on emergence percentages. Their values are given in Table 161 as they were affected by the N, P and K Levels.

TABLE 161 : The Influence of N,P & K (Main effects) on Emergence %ages.

Nutr. Level	Means of 32 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	75.51	93.39	74.6	92.95	77.1	95.02
2nd	76.4	94.47	76.9	94.86	74.4	92.77
5% LSD	4.89		4.89		4.89	

(b) Emergence Rate

None of the nutrients examined or their interactions had a significant effect on emergence rate. The values of the emergence rate due to the main effects of N, P and K are given in Table 162.

TABLE 162 : The Influence of N,P & K (Main Effects) on Emergence Rate

Nutrt. Level	Means of 32 Plants		
	N	P	K
1st	13.064	13.043	13.063
2nd	13.245	13.266	13.246
5% LSD	0.267	0.267	0.267

(c) Seedling Dry Weight

From the analysis of variance it was found that none of the nutrients examined had a significant effect on seedling dry weight. Table 163 gives the values of seedling dry weight due to N, P and K main effects.

TABLE 163 : The Influence of N, P and K (Main effects) on Seedling Dry Weight

Nutr. Level	Means of 32 Plants (g)		
	N	P	K
1st	0.366	0.367	0.373
2nd	0.377	0.377	0.371
5% LSD	0.023	0.023	0.023

(d) Percentage of Very Weak Seedlings

From the analysis of variance it was found that none of the nutrients examined had a significant effect on the percentages of very weak seedlings. Table 164 gives these percentages as affected by the N, P and K levels.

TABLE 164 : The Influence of N, P and K (Main effects) on Percentage of Very Weak Seedlings

Nutr. Level	Means of 32 Plants					
	N		P		K	
	Angles	%	Angles	%	Angles	%
1st	17.7	9.24	16.8	8.35	17.9	9.45
2nd	17.5	9.04	18.3	9.86	17.2	8.74
5% LSD (angles)	4.22		4.22		4.22	

(e) Percentage of Weak Seedlings

None of the nutrients examined or their interactions had a significant effect on percentages of weak seedlings. These percentages due to the N, P and K main effects are given in Table 165.

TABLE 165 : The Influence of N, P and K (Main effects) on Percentage of Weak Seedlings

Nutr. Level	Means of 32 Plants		
	N	P	K
1st	48.8	50.7	48.7
2nd	49.8	47.9	49.8

5% LSD	5.61	5.61	5.61

(f) Percentage of Vigorous Seedlings

None of the nutrients examined or their interactions had a significant effect on the percentages of vigorous seedlings. Table 166 gives these percentages as affected by the N, P and K main effects.

TABLE 166 : The Influence of N, P and K (Main effects) on Percentage of Vigorous Seedlings

Nutr. Level	Means of 32 Plants		
	N	P	K
1st	39.1	38.3	40.3
2nd	39.8	40.7	38.6

5% LSD	5.53	5.53	5.53

Cold Test

(a) Percentage of Emergence

From the analysis of variance it was found that the percentage of emergence in the cold test was significantly affected by the P K interaction only, at 5% level. Tables 167 and 168 give these percentages as affected by the N, P and K main effects and by the P K interaction.

TABLE 167 : The Influence of N, P and K (Main effects) on Percentage of Emergence in Cold Test

Nutrt. Level	Means of 32 Plants		
	N	P	K
1st	47.5	45.8	46.0
2nd	44.6	46.4	46.1
5% LSD	5.69	5.69	5.69

TABLE 168 : The Influence of P K Interaction on Percentage of Emergence in Cold Test

Nutrient	Means of 16 Plants	
	K_1	K_2
P_1	42.5	49.0
P_2	49.5	43.3

5% LSD = 8.05

It can therefore be observed that the highest percentages were achieved with the P_2K_1 and P_1K_2 combinations.

(b) Percentage of Mortality

From the analysis of variance it was found that the percentage of mortality in the cold test was significantly affected by the PK interaction only, at 1% level. Tables 169 and 170 give these percentages as affected by the N, P and K and the P K interaction.

TABLE 169 : The Influence of N, P and K (Main effects) on Percentage of Mortality in the Cold Test

Nutrt. Level	Means of 32 Plants		
	N	P	K
1st	46.4	46.4	47.5
2nd	49.5	49.5	48.4
5% LSD	5.53	5.53	5.53

TABLE 170 : The Influence of P K Interaction on Percentage of Mortality in the Cold Test

Nutrient	Means of 16 Plants	
	K_1	K_2
P_1	50.0 ab	42.8 b
P_2	45.0 b	54.0 a

5% LSD = 7.82

Data followed by different letters (a,b) are significantly different.

It can therefore be observed that the highest percentages of mortality were achieved with the P_2K_2 and P_1K_1 combinations.

Electrical Conductivity

From the analysis of variance it was found that the electrical conductivity of the leakage of the soaked seeds, measured in microsiemens per g (µS/g), was not affected by the nutrients examined or by their interactions.

Table 171 gives the values of the electrical conductivity as affected by the N, P and K main effects.

TABLE 171 : The Influence of N, P and K (Main effects) on Electrical Conductivity

Nutrient Level	Means of 16 Plants (µS/g)		
	N	P	K
1st	43.77	43.50	44.44
2nd	44.72	44.99	44.04
5% LSD	3.29	3.29	3.29

Seed Total Nitrogen Content

From the analysis of variance it was found that the total nitrogen content of the seed was affected by the phosphorus and potassium interaction only, at 1% level of significance. Tables 172 and 173 give the seed total nitrogen content in percentage of dry matter due to N, P and K main effects and due to P K interaction.

TABLE 172 : The Influence of N, P and K (Main effects) on Seed Total Nitrogen Content

Nutrt. Level	Means of 12 Plants		
	N	P	K
1st	3.701	3.786	3.583
2nd	3.662	3.577	3.779
5% LSD	0.232	0.232	0.232

TABLE 173 : The Influence of P K Interaction on Seed Total Nitrogen Content

Nutrient	Means of 6 Plants	
	K_1	K_2
P_1	3.870 a	3.702 a
P_2	3.297 b	3.857 a

5% LSD = 0.328

Data followed by different letters (a,b) are significantly different.

It can be observed that the highest percentages of nitrogen content in the seed were achieved with the combinations P_1K_1, P_2K_2, P_1K_2.

Seed Phosphorus Content

After the analysis of variance it was found that none of the nutrients examined or their interactions had a significant effect on seed phosphorus content.

Table 174 gives the percentages of phosphorus content in the seeds as affected by the N, P and K main effects.

TABLE 174 : The Influence of N, P and K (Main effects) on Seed Phosphorus Content

Nutrient Level	Means of 12 Plants		
	N	P	K
1st	0.447	0.425	0.417
2nd	0.417	0.439	0.447
5% LSD	0.042	0.042	0.042

Seed Potassium Content

After the analysis of variance it was found that the seed potassium content was significantly affected by the nitrogen levels at 1% level and by the phosphorus levels at 5% level.

Table 175 gives the potassium content as percentages per g. of dry seed weight as affected by the N, P and K main effects.

TABLE 175 : The Influence of N, P and K (Main effects) on Seed Potassium Content

Nutrient Level	Means of 12 Plants		
	N	P	K
1st	1.040 a	1.027 a	1.013 a
2nd	0.953 b	0.967 b	0.980 a
5% LSD	0.052	0.052	0.052

Data followed by different letters (a,b) within a column are significantly different.

It can therefore be observed that higher percentages of potassium content in the seeds were achieved with the 1st level of nitrogen and the 1st level of phosphorus.

2. PROGENY PERFORMANCE

Experiment No. 5

Early Plant Growth

Seven days after the seed emergence and before thinning, the seedling height was measured and the mean seedling height was calculated. After the analysis of variance it was found that the seedling height was significantly affected by the seed lots at 1% level, but not by the nutrient regime (Tables 176 and 177). Examining the results it can be seen that the highest seedlings were produced by the seed lots Nos. 1, 5, 42, 3, 19 and 37. These seed lots resulted from mother plants which had received the following nutrient combinations respectively: N_1 P_1 K_1 M_1, N_1 P_1 K_3 M_1, N_3 P_1 K_3 M_2, N_1 P_1 K_2 M_1, N_2 P_1 K_1 M_1 and N_3 P_1 K_1 M_1. The shortest seedlings were produced by the seed lots Nos. 7, 13, 50, 36 and 18, lots which were produced by mother plants receiving the following nutrient combinations respectively: N_1 P_2 K_1 M_1, N_1 P_3 K_1 M_1, N_3 P_3 K_1 M_2, N_2 P_3 K_3 M_2 and N_1 P_3 K_3 M_2.

Final Plant Growth

After harvesting, the dry weight of the stems (without leaves) was measured. From the analysis of variance it was found that this dry weight was significantly affected by the nutrient regime at 1% level, but not by the seed lots or their interaction. Looking at the results

(Tables 176 and 177) it can be seen that the plants which have received the 'High' nutrient regime produced higher stem dry weight.

Days to First Flower

There is evidence that the number of days from sowing to first flower is only affected by the nutrient regime (Tables 176 and 177). Plants receiving the 'High' nutrient regime had the first flower earlier than plants receiving the 'Low' nutrient regime. Although this effect on mean days to first flower is highly significant (1% level), in practice it is not important, as the difference between the two means due to the two different nutrient regimes is less than 1 day.

Mean Days to Harvest

The mean days from sowing to harvesting were calculated. The analysis of variance for these figures showed that the nutrient regime significantly affected the time from sowing to harvesting at 1% level (Tables 176 and 177). Also the interaction between nutrient regime and seed lots affected this duration significantly at 5% level of significance (Table 178). Examining the results it can be seen that the plants under the 'Low' nutrient regime reached maturity earlier. Although the differences in these values were found to be significant in practice it is probably not important as their differences are less than 1 day.

TABLE 176 : The Influence of Nutrient Regime on Plant Growth (Early and Late), Days to 1st Flower and Mean time to Harvest

Nutrient Regime	Seedling Height (in cm)	Stem Dry Matter (in g.)	Days to First Flower	Mean Time to Harvest (Days)
Low	7.48 a	1.41 b	33.68 a	83.31 b
High	7.58 a	7.02 a	32.95 b	83.69 a
5% LSD	0.23	0.28	0.36	0.19
No. of Observations	56	56	56	56

Data followed by different letters (a,b) within a column are significantly different.

TABLE 177 : The Influence of Seed Lots on Subsequent Plant Growth (Early & Late), Days to 1st Flower and Mean Time to Harvest (Means of 8 Observations)

No. of Seed Lot	Seedling Height (in cm)	Stem Dry Matter (in g.)	Days to First Flower	Mean Time to Harvest (Days)
1	8.30 a	4.15	33.12	83.57
3	8.00 ab	4.34	32.87	83.26
5	8.05 ab	4.21	33.75	83.66
7	6.70 f	3.81	33.37	83.59
13	6.75 f	3.91	33.50	83.58
18	7.18 cdef	3.94	33.75	83.56
19	7.84 ab	4.00	33.75	83.64
36	7.00 def	3.87	33.25	83.27
37	7.77 abc	4.45	33.12	83.32
42	8.02 ab	4.33	32.87	83.40
48	7.49 bcde	4.36	33.87	85.59
50	6.92 ef	4.66	33.12	83.49
52	7.61 bcd	4.60	33.37	83.41
54	7.76 abc	4.33	32.62	83.67
5% LSD	0.62	0.75	0.95	0.51

Data followed by different letters (a-f) within a column are significantly different.

TABLE 178 : The Influence of Nutrient Regime and Seed Lot Interaction on Mean Days to Harvest

No. of Seed Lot	Nutrient Regime	
	'Low'	'High'
1	83.69	83.45
3	83.25	83.26
5	83.78	83.53
7	83.85	83.34
13	83.12	84.03
18	83.13	83.98
19	83.48	83.80
36	82.87	83.66
37	82.68	83.97
42	83.23	83.58
48	83.27	83.91
50	83.06	83.92
52	83.38	83.44
54	83.58	83.76

5% LSD = 0.725

(The data are means of 4 observations).

Number of Pods Per Plant

It was found from the analysis of variance that only the nutrient regime significantly affected the number of pods per plant at 1% level (Tables 179 and 180). Looking at the results it can be seen that more pods were produced from plants under the 'High' nutrient regime.

Number of Seeds Per Plant

Also the number of seeds per plant were found to be significantly affected only by the nutrient regime at 1% level of significance (Tables 179 and 180). More seeds were produced from plants under the 'High' regime.

Number of Seeds Per Pod

Although the number of seeds per pod was found to be significantly affected by the nutrient regime only (Tables 179 and 180), in practice this is not important as the difference between the means under the two different nutrient regimes is less than 1 seed.

Seed Yield

It was found from the analysis of variance that only the nutrient regime significantly affected the seed yield at 1% level. Tables 179 and 180 give the seed yield as affected by the two nutrient regimes and the 14 different seed lots. It can be seen that plants under the 'High' nutrient regime produced a higher seed yield.

Seed to Empty Pod Ratio (S:EP)

This ratio was found to be significantly affected by nutrient regime only at 1% level of significance. The S:EP values can be seen in Tables 179 and 180 as affected by the two nutrient regimes and the different seed lots. Plants under the 'High' nutrient regime produced pods with higher S:EP ratio than plants under the 'Low' nutrient regime.

TABLE 179 : The Influence of Nutrient Regime on Number of Pods and Seeds Per Plant, Number of Seeds Per Pod and Seed Yield (Means of 56 observations)

Nutrient Regime	No. of Pods Per Plant	No. of Seeds Per Plant	No. of Seeds Per Pod	Seed Yield Per Plant (g.)	S:EP Ratio
Low	4.68 b	20.0 b	4.33 b	8.40 b	2.634 b
High	23.32 a	120.6 a	5.15 a	56.29 a	3.080 a
5% LSD	0.77	4.92	0.21	1.56	0.093

Data followed by different letters (a,b) within a column are significantly different.

TABLE 180 : The Influence of Seed Lots on Numbers of Pods Per Plant, Seeds Per Plant and Per Pod and Seed Yield (Means of 8 Observations)

No. of Seeds Lot	No. of Pods Per Plant	No. of Seeds Per Plant	No. of Seeds Per Pod	Seed Yield Per Plant (g.)	S:EP Ratio
1	13.88	70.0	4.70	32.03	2.916
3	14.50	68.1	4.57	31.71	2.745
5	13.38	69.5	4.77	31.67	2.786
7	13.63	69.4	4.97	32.22	2.955
13	14.00	71.4	4.93	33.53	2.904
18	12.63	63.6	4.76	30.38	2.962
19	13.75	68.0	4.25	31.89	2.741
36	14.00	73.0	5.13	33.15	3.067
37	14.13	68.4	4.52	31.35	2.760
42	14.00	70.9	4.88	32.38	2.765
48	14.13	66.7	4.43	31.74	2.822
50	13.88	72.5	5.12	33.04	2.947
52	16.25	77.7	4.40	35.00	2.690
54	13.88	75.0	4.94	32.68	2.935
5% LSD	2.03	13.03	0.57	4.12	0.246

Seed Size

(a) Weight of Individual Seeds

From the analysis of variance it was found that the mean seed weight was significantly affected by the nutrient regime only, at 1% level of significance (Tables 181 and 182). Examining these results it can be seen that the plants under the 'High' nutrient regime produced heavier seeds than the plants under the 'Low' nutrient regime.

(b) 100 Seed Weight

The 100 seed weight was found to be significantly affected by the nutrient regime at 1% level and by the nutrient regime, seed lot interaction at 5% level. Looking at the results (Tables 181, 182 and 183) it can be seen that the 'High' nutrient regime resulted in the production of heavier seeds. Examining the interaction results (Table 183) it can be observed that, for most of the seed lots the dominant factor is the nutrient regime (heavier seeds with the 'High' and lighter seeds with the 'Low'). But the seed lots Nos. 52, 5, 1 and 7 produced seeds with similar 100 seed weight under both nutrient regimes and the seed lot No. 42 produced the heaviest seed with the 'High' nutrient regime and the lightest with the 'Low'.

TABLE 181 : The Influence of Nutrient Regime on Seed Size
(Individual Seed Weight and 100 Seed Weight)

Nutrient Regime	Seed Weight (g)	100 Seed Weight (g)
Low	0.425 b	42.04 b
High	0.474 a	47.86 a
5% LSD	0.010	1.13

Data followed by different letters (a,b) within a column are significantly different.

TABLE 182 : The Influence of Seed Lots on Seed Size
(Individual Seed Weight and 100 Seed Weight)

No. of Seed Lot	Seed Weight (g)	100 Seed Weight (g)
1	0.457	45.22
3	0.454	45.77
5	0.438	43.51
7	0.457	45.56
13	0.455	44.82
18	0.464	46.96
19	0.463	46.01
36	0.433	42.74
37	0.445	44.11
42	0.430	44.55
48	0.461	45.89
50	0.435	43.07
52	0.451	45.60
54	0.448	45.47
5% LSD	0.027	2.99

TABLE 183 : The Influence of Nutrient Regime/Seed Lot Interaction on Seed Size

No. of Seed Lot	Nutrient Regime (g)	
	'Low'	'High'
1	43.65	46.80
3	42.20	49.35
5	42.40	44.62
7	43.72	47.40
13	42.05	47.60
18	43.80	50.12
19	43.25	48.77
36	38.35	47.12
37	41.05	47.17
42	38.35	50.75
48	42.42	49.35
50	39.70	46.45
52	45.30	45.90
54	42.27	48.67

5% LSD = 4.22

Seedling Evaluation Test

(a) Emergence Percentage

The emergence percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that from the factors examined only the nutrient regime had a main effect at 1% level, and the interaction nutrient regime/seed lots at 5% level. Examining the results in Tables 184 and 185 it can be seen that the 'Low' nutrient regime resulted in high emergence percentages compared with those from the 'High' nutrient regime. From the results due to the interaction (Table 186) it can be observed that under the 'Low' nutrient regime the seed produced from the different seed lots performed similarly (89-100% emergence) but under the 'High' regime the emergence percentages were between 47% and 97%.

TABLE 184 : The Influence of Nutrient Regime on Emergence Percentage

Nutrient Regime	Means of 56 Plants	
	Angles	%
Low	88.7 a	99.95
High	60.1 b	75.17
5% LSD	3.7	

Data followed by different letters (a,b) within a column are significantly different.

TABLE 185 : The Influence of Seed Lots on Emergence Percentage

No. of Seed Lot	Means of 8 Plants	
	Angles	%
1	67.5	85.35
3	79.8	96.84
5	71.2	89.58
7	75.1	93.42
13	75.7	93.92
18	68.3	86.37
19	76.1	94.21
36	79.4	96.63
37	73.6	92.07
42	80.2	97.12
48	82.8	98.42
50	66.7	84.31
52	73.8	92.26
54	71.3	89.70
5% LSD	9.8	

TABLE 186 : The Influence of the Nutrient Regime and Seed Lot Interaction on Emergence Percentage

No. of Seed Lot	Nutrient Regimes			
	'Low'		'High'	
	Angles	%	Angles	%
1	85.4	99.35	49.6	57.99
3	85.4	99.35	74.1	92.53
5	90.0	100.00	52.3	62.60
7	90.0	100.00	60.3	75.45
13	90.0	100.00	61.4	77.08
18	90.0	100.00	46.7	52.96
19	90.0	100.00	62.1	78.17
36	90.0	100.00	68.9	87.04
37	90.0	100.00	57.3	70.81
42	90.0	100.00	70.4	88.80
48	90.0	100.00	75.6	93.80
50	90.0	100.00	43.3	47.03
52	90.0	100.00	57.7	71.43
54	80.8	97.43	61.8	77.67

5% LSD (for the angles) = 13.9

(b) Emergence Rate

From the analysis of variance it was found that the emergence rate was significantly affected only by the nutrient regime at 5% level. From Tables 187 and 188 it can be seen that the emergence rate was higher in seeds from the 'Low' nutrient regime.

(c) Seedling Dry Weight

The seedling dry weight was not significantly affected by the nutrient regime or by the seed lots (Tables 187 and 188).

(d) Percentage of Vigorous Seedlings

These percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that from the factors examined only the nutrient regime had a significant effect at 1% level. From Tables 187 and 188 it can be seen that these percentages were higher in seeds from the 'Low' nutrient regime.

TABLE 187 : The Influence of Nutrient Regime on Emergence Rate Seedling Dry Weight and Percentage of Vigorous Seedlings

Nutrient Regime	Emergence Rate	Seedling Dry Weight (g)	Vigorous Seedlings	
			Angles	%
Low	5.68 a	0.449 a	82.8 a	98.45
High	5.59 b	0.458 a	71.5 b	89.96
5% LSD	0.08	0.023	5.5	

Data followed by different letters (a,b) within a column are significantly different.

TABLE 188 : The Influence of Seed Lots on Emergence Rate, Seedling Dry Weight and Percentage of Vigorous Seedlings

No. of Seed Lot	Emergence Rate	Seedling Dry Weight (g)	Vigorous Seedlings	
			Angles	%
1	5.65	0.471	78.1	95.78
3	5.60	0.452	76.9	94.88
5	5.67	0.460	73.7	92.09
7	5.57	0.438	70.9	89.31
13	5.61	0.453	79.5	96.67
18	5.54	0.447	79.2	96.52
19	5.61	0.449	75.9	94.09
36	5.58	0.449	75.8	93.96
37	5.65	0.488	83.3	98.63
42	5.72	0.446	81.1	97.62
48	5.67	0.416	73.8	92.24
50	5.66	0.472	79.2	96.52
52	5.66	0.466	82.8	98.44
54	5.66	0.438	70.3	88.64
5% LSD	0.21	0.061	14.6	

(Data are means of 8 Plants)

3. HARVEST STAGES AND POD POSITION ON THE MOTHER PLANT

Experiment No. 6

Plant Growth, Number of Pods and Number of Seeds Per Plant

In Table 189 the stem dry weight, number of pods and number of seeds per plant and per harvest stage are given. The analysis of variance showed that none of these parameters was affected by the harvest stage.

TABLE 189 : The Stem Dry Weight, Number of Pods and Number of Seeds Per Plant and Per Harvest Stage

Harvest Stage	Stem Dry Matter (g)	Pods Per Plant	Seeds Per Plant
1st	4.81	11.9	57.7
2nd	4.02	12.1	56.3
3rd	3.26	10.9	52.2
4th	3.25	10.9	54.9
5th	4.59	12.3	53.4
6th	3.91	11.4	56.1
5% LSD	1.17	2.6	11.3

(The data are means of 16 Plants)

Number of Seeds Per Pod

From the analysis of variance it was found that the number of seeds per pod was significantly affected by the harvest stage and the pod position on the plant.

Table 190 shows that in the 2nd and 5th harvests the number of seeds per pod was smaller than in the other harvests and the pods from the main axis contained more seeds than pods from the secondary branches. Although these differences are significant they are not important in practice, as they are less than 1, which is the smallest difference in seeds between two pods.

TABLE 190 : The Influence of Harvest Stage and Pod Position on the Mother Plant on Number of Seeds Per Pod

Harvest Stage	Number of Seeds Per Pod (1)	Pod Position	Number of Seeds Per Pod (2)
1st	4.88 a	Main Axis	5.11 a
2nd	4.64 ab	Secdry. Branches	4.48 b
3rd	4.88 a		
4th	5.04 a		
5th	4.42 b		
6th	4.91 a		
5% LSD	0.41		0.24

(1) = Means of 8 Plants (2) = Means of 24 Plants

Data followed by different letters (a,b) within a column are significantly different.

Seed Yield

The seed yield per plant was not significantly affected by the harvest stages.

Table 191 shows the seed yield in g. per plant. Examining this table it can be seen that, although there is no significant effect due to the harvest stage there is a trend for higher yields from the 1st harvest up to the 5th and then a slight decrease in the 6th harvest.

TABLE 191 : The Influence of Harvest Stages on Seed Yield Per Plant

Harvest Stage	Seed Yield Per Plant (g) (Means of 16 Plants)
1st	16.45
2nd	20.60
3rd	20.85
4th	22.12
5th	23.17
6th	22.57
5% LSD	4.56

Table 192 shows the seed yield distribution, in percentages, on the two different positions (main axis, secondary branches). It can be seen that the contribution of the secondary branches in the total seed yield is considerable, from 40.40% up to 51.72%. At each harvest stage the seed moisture content has been measured as previously described, for both seed lots, i.e. from the main axis and from the secondary branches. These seed moisture contents expressed as percentages of the fresh weight are given in Table 193.

TABLE 192 : Distribution of Seed Yield From Each Plant on the Main Axis and on the Secondary Branches

Harvest Stage	Percentage of Seed Yield On	
	Main Axis	Secondary Branches
1st	57.85	42.15
2nd	55.52	44.48
3rd	48.28	51.72
4th	59.60	40.40
5th	48.42	51.58
6th	55.97	44.03

TABLE 193 : Seed Moisture Content Per Pod Position and at Each Harvest Stage as Percentage of Fresh Weight

Harvest Stage	Main Axis	Secondary Branches
1st	63.00	68.40
2nd	57.20	61.69
3rd	54.79	57.07
4th	38.36	57.74
5th	16.79	39.63
6th	16.45	22.53

Seed to Empty Pod Ratio (S:EP)

From the analysis of variance it was found that the S:EP ratio was significantly affected by both the harvest stage and the pod position on the plant at 5% and 1% levels respectively.

Table 194 gives the S:EP ratio values as they were affected by the harvest stages and the pod position (main effects). It can be seen that the poorest ratio was achieved at the 1st harvest and from the two positions the main axis produced pods with higher ratio than the secondary branches.

TABLE 194 : The Influence of Harvest Stage and Pod Position (Main effects) on S:EP Ratio

Harvest Stage	S:EP Ratio (1)	Pod Position	S:EP Ratio (2)
1st	3.132 b	Main Axis	3.717 a
2nd	3.454 ab	Secdry. Branches	3.215 b
3rd	3.561 a		
4th	3.707 a		
5th	3.417 ab		
6th	3.524 a		
5% LSD	0.331		0.191

(1) = Means of 8 Plants (2) = Means of 24 Plants

Data followed by different letters (a,b) within a column are significantly different.

Seed Size Determination

(a) Weight of Individual Seeds

The mean seed weight has been calculated as in previous experiments. From the analysis of variance it was found that the mean seed weight was signficantly affected by the harvest stages, by the pod position on the mother plant and by their interaction at 1% level of significance.

Tables 195 and 196 give the mean seed weight per harvest stage and per pod position. It can be observed that the heaviest seeds were achieved with the 5th harvest and in the pods on the main axis (M). The lightest seeds were achieved with the 1st harvest and in the pods on the secondary branches (S).

Table 197 gives the mean seed weight due to the interaction harvest stages x pod position. From this table it can be seen that heavier seeds were produced on the main axis and harvested at the 5th stage, followed by seeds produced on the main axis and harvested at the 4th, 3rd and 6th stages and seed produced on the secondary branches and harvested at the 5th stage. Light seeds were produced on the main axis and harvested at the 1st stage and on the secondary branches and harvested at the 1st and 2nd stages.

TABLE 195 : The Influence of Harvest Stages (Main effects) on Individual Seed Weight and 100 Seed Weight

Harvest Stage	Individual Seed Weight (g) (1)	100 Seed Weight (g) (2)
1st	0.321 d	33.71 d
2nd	0.405 c	42.19 c
3rd	0.439 c	45.60 b
4th	0.448 b	46.52 b
5th	0.482 a	50.10 a
6th	0.444 b	47.03 b
5% LSD	0.021	1.52

Data followed by different letters (a-d) within a column are significantly different.

(1) = Means of 8 Plants (2) = Means of 20 Plants.

TABLE 196 : The Influence of Pod Position (Main effects) on Individual Seed Weight and 100 Seed Weight

Pod Position	Individual Seed Weight (g) (1)	100 Seed Weight (g) (2)
M	0.454 a	47.04 a
S	0.393	41.35 b
5% LSD	0.012	0.88

Data followed by different letters (a,b) within a column are significantly different.

(1) = Means of 24 Plants (2) = Means of 60 Plants

TABLE 197 : The Influence of Harvest Stages x Pod Position Interaction on Individual Seed Weight

Harvest Stage	Means of 4 Plants (g)	
	Pod Position	
	Main Axis	Secondary Branches
1st	0.378 e	0.264 f
2nd	0.447 bc	0.363 e
3rd	0.466 b	0.412 d
4th	0.468 b	0.427 cd
5th	0.500 a	0.464 b
6th	0.463 b	0.425 cd

5% LSD : 0.029

Data followed by different letters (a-f) are significantly different.

(b) <u>100 Seed Weight</u>

The analysis of variance showed similar results to those with the individual seed weight. The 100 seed weight due to the harvest stages and pod position on the mother plant is given in Tables 195 and 196. Again the 5th harvest stage and the position 'M' had the best effect on the 100 seed weight.

Table 198 gives the 100 seed weight due to the interaction between harvest stages and pod position, and in this case the results are similar to those for the individual seed weight.

TABLE 198 : The Influence of Harvest Stage x Pod Position Interaction on 100 Seed Weight

Harvest Stage	Means of 10 Plants (g)	
	Pod Position	
	Main Axis	Secondary Branches
1st	39.08 e	28.35 f
2nd	46.60 bc	37.80 e
3rd	48.24 b	42.98 d
4th	48.23 b	44.80 cd
5th	51.87 a	48.32 b
6th	48.21 b	45.85 c

5% LSD : 2.14

Data followed by different letters (a-f) are significantly different.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that only the harvest stages significantly affected the germination percentage at 1% level.

Tables 199 and 200 give these percentages due to the harvest stages and to the pod position on the mother plant. Examining these percentages it can be seen that the early harvests gave seed with higher germination percentages compared with those from the late harvests, but their differences, although significant are very small. Seeds from different positions on the plant had similar germination percentages.

(b) Germination Rate

From the analysis of variance it was found that the germination rate was significantly affected by the harvest stage at 1% level and by the interaction harvest stage x pod position at 5% level. Examining Tables 199 and 200, where the germination rate values are given, it can be observed that the germination rate was higher in seeds from the 1st harvest followed by seed from the 2nd harvest and then all the others. Seeds from different positions on the plant had similar germination rates.

TABLE 199 : The Influence of Harvest Stages on Germination Percentage, Germination Rate and Seedling Dry Weight

Harvest Stage	Means of 12 Plants			
	Germination Percentage		Germination Rate	Seedling Dry Weight (g)
	Angles	%		
1st	88.1 a	99.89	15.43 a	0.193 d
2nd	86.1 a	99.55	14.87 b	0.247 c
3rd	72.1 bc	90.57	14.37 c	0.268 b
4th	65.8 c	83.25	14.34 c	2.282 ab
5th	78.1 b	95.73	14.40 c	0.297 a
6th	67.1 c	84.81	14.21 c	0.278 b
5% LSD	7.7		0.318	0.016

Data followed by different letters (a-d) within a column are significantly different.

TABLE 200 : The Influence of Pod Position on Germination Percentage, Germination Rate and Seedling Dry Weight.

Pod Position	Means of 36 Plants			
	Germination Percentage		Germination Rate	Seedling Dry Weight (g)
	Angles	%		
M	76.4 a	94.48	14.52 a	0.279 a
S	76.1a	94.17	14.69 a	0.243 b
5% LSD	4.5		0.183	0.009

Data followed by different letters (a,b) within a column are significantly different.

In Table 201 the germination rates due to the interaction harvest stages x pod position are given. From this table it can be observed that the combination 1st harvest x 'S' position gave the highest germination rate, followed by the combinations, 2nd harvest x 'S' position and 1st harvest x 'M' position. The lowest germination rate was given by the combination 6th harvest x 'S' position.

TABLE 201 : The Influence of the Interaction Harvest Stages x Pod Position on Germination Rate

Harvest Stage	Means of 6 Plants	
	Pod Position	
	Main Axis	Secondary Branches
1st	15.14 b	15.72 a
2nd	14.55 c	15.20 b
3rd	14.40 cd	14.34 cd
4th	14.25 cd	14.43 c
5th	14.31 cd	14.49 c
6th	14.43 c	13.98 d

5% LSD : 0.45

Data followed by different letters (a-d) are significantly different.

(c) Seedling Dry Weight

The seedling dry weight was significantly affected by harvest stages, pod position on the mother plant and by their interaction, all at 1% level of significance. The main effects of harvest stages and pod position on seedling dry weight are given in Tables 199 and 200, and it can be seen that the heaviest seedlings were produced by seeds from the 5th and 4th harvests and by seeds from the 'M' position (main axis). The lightest seedlings were produced by seeds from the 1st harvest and by seeds from the 'S' position (secondary branches).

The seedling dry weights due to the interaction harvest stage x pod position are given in Table 202. It can be seen that the heaviest seedlings were produced by seed from the combinations 5th harvest stage x 'M' position and 4th harvest stage x 'M' position, and the lightest seedlings were produced by seeds from the combinations 1st harvest stage x 'S' position; 2nd harvest stage x 'S' position and 1st harvest stage x 'M' position.

TABLE 202 : The Influence of the Interaction Harvest Stages x Pod Position on Seedling Dry Weight

Harvest Stage	Pod Position (Means of 6) (g)	
	Main Axis	Secondary Branches
1st	0.225 d	0.162 e
2nd	0.282 b	0.211 d
3rd	0.284 b	0.253 c
4th	0.290 ab	0.274 bc
5th	0.310 a	0.283 b
6th	0.283 b	0.273 bc

5% LSD : 0.023

Data followed by different letters (a-d) are significantly different.

Seedling Evaluation Test

(a) Emergence Percentage

The emergence percentages, after their transformation into angles, were statistically analysed. From the analysis of variance it was found that there was a significant effect from harvest stages at 5% level and from pod position at 1% level. Examining Tables 203 and 204, where the emergence percentages are given, it can be observed that, in the case of harvest stages, the best percentage was obtained with seed from the 1st harvest. There is a slight decrease in emergence percentage of seed from the other harvest stages. In the case of pod position, the seed from the main axis (M) had a better emergence than seed from the secondary branches (S). Although these difference are significant, they are very small and therefore not of practical importance.

(b) Emergence Rate

The emergence rate was significantly affected by harvest stages at 1% level and by pod position at 5% level. Tables 203 and 204 give the values of this rate and it can be seen that the highest rate was achieved from seed harvested early (1st harvest). Seeds from all the other harvests gave similar emergence rates. Comparing the emergence rate in seed from the two different positions it can be observed that those from the 'S' position were slower.

(c) Seedling Dry Weight

From the analysis of variance it was found that the seedling dry weight was significantly affected by the harvest stages and by the pod position both at 1% level. In Tables 203 and 204, where the seedling dry weights are given, it can be seen that the heaviest seedlings were produced from seed harvested at the 5th stage and the lightest from seed harvested at the 1st stage. Seeds from the 'M' position produced heavier seedlings than those from the 'S' position.

TABLE 203 : The Influence of Harvest Stage on Emergence Percentage, Emergence Rate and Seedling Dry Weight

Harvest Stage	Means of 8 Plants			
	Emergence Percentage		Emergence Rate	Seedling Dry Weight (g)
	Angles	%		
1st	87.1 a	99.75	6.92	0.186 c
2nd	85.7 ab	99.43	6.55	0.215 ab
3rd	81.1 abc	97.60	6.56	0.211 ab
4th	78.8 c	96.21	6.58	0.206 b
5th	79.6 bc	96.73	6.40	0.224 a
6th	78.2 c	95.85	6.61	0.214 ab
5% LSD	6.24		0.22	0.017

Data followed by different letters (a-c) within a column are significantly different.

TABLE 204 : The Influence of Pod Position on Emergence Percentage, Emergence Rate and Seedling Dry Weight

Pod Position	Means of 24 Plants			
	Emergence Percentage		Emergence Rate	Seedling Dry Weight (g)
	Angles	%		
M	85.3 a	99.34	6.53 b	0.219 a
S	78.1 b	95.78	6.67 a	0.199 b

5% LSD : 3.61 0.13 0.010

Data followed by different letters (a,b) within a column are significantly different.

(d) Percentage of Vigorous Seedlings

These percentages were transformed into angles and then statistically analysed. It was found that the percentage of vigorous seedlings were significantly affected by the harvest stage at 5% level and by the pod position at 1% level.

Table 205 gives these percentages per harvest stage and per pod position. It can be observed that seeds from the 1st harvest produced the smallest number of vigorous seedlings and seed from all the other harvests produced similar numbers. Also seeds on the 'M' position produced more vigorous seedlings than seeds on the 'S' position.

TABLE 205 : The Influence of Harvest Stage and Pod Position (Main effects) on Percentage of Vigorous Seedlings

Harvest Stage	Means of 8 Plants Vigorous Seedlings Angles	Means of 8 Plants Vigorous Seedlings %	Pod Position	Means of 24 Plants Vigorous Seedlings Angles	Means of 24 Plants Vigorous Seedlings %
1st	59.8 b	74.70	M	75.4 a	93.65
2nd	73.3 a	91.74	S	64.7 b	81.74
3rd	72.6 a	91.06			
4th	68.0 ab	85.97			
5th	75.7 a	93.90			
6th	71.0 a	89.40			

5% LSD : 10.02 5.78

Data followed by different letters (a,b) within a column are significantly different.

Experiment No. 7

Flowering Sequence

During the flowering period the number of new flowers per branch was recorded in the 40 slected plants. These observations are given in Table 206.

From the data in Table 206 the mean time of flowering per branch and per position were calculated using the formula:

$$\text{Mean time of flowering} = \frac{F_1 T_1 + F_2 T_2 + \ldots\ldots F_n T_n}{F_1 + F_2 + \ldots\ldots F_n}$$

where: F_1 = number of flowers opened at time T_1.

F_2 = number of flowers opened at time T_2.

The calculated mean times of flowering are given in Table 207.

TABLE 206 : Flowering Sequence of *Phaseolus vulgaris* (cultivar 'Cascade') at Time, Number of Flowers Per Position and Per Plant. T.L. = Trifoliate Leaf. P.L. = Primary Leaves

Date of Observation	Number of Flowers (Total of 40 Plants)									
	Top		1st T.L.		2nd T.L.		3rd T.L.		P.L.	
	'M'	'S'	'M'	'S'	'M'	'S'	'M'	'S'	'S'	
1 (13/9)	19	-	-	-	-	-	-	-	-	
2 (15/9)	105	-	19	-	2	-	12	-	1	
3 (17/9)	170	-	95	-	51	-	65	-	36	
4 (19/9)	86	-	89	-	75	-	35	-	147	
5 (21/9)	38	2	54	11	63	1	10	3	263	
6 (23/9)	18	12	25	29	29	26	10	20	234	
7 (25/9)	8	19	10	46	15	61	7	61	155	
8 (27/9)	7	8	4	27	5	67	3	67	81	
9 (29/9)	1	1	-	12	1	27	-	28	25	
10 (1/10)	-	1	-	1	-	5	-	9	2	
Totals	455	43	296	126	241	187	142	188	944	2622
Flowers/plant	11.37	1.07	7.40	3.15	6.02	4.67	3.55	4.70	23.60	65.55
% Flowers	17.35	1.64	11.29	4.80	9.19	7.13	5.42	7.17	36.00	-

No. of Flowers in 'M' Position = 1134 or 43.25%

No. of Flowers in 'S' Position = 1488 or 56.75%

TABLE 207 : The Mean Time of Flowering Per Branch and Per Position ('M' and 'S')

Branches/ Positions	Mean Time of Flowering (1,2...Time of Obs)	Date (Approximately)
Top 'M'	3.33	18th September
'S'	6.93	25th September
1st T.L. 'M'	4.06	19th September
'S'	7.02	25th September
2nd T.L. 'M'	4.56	20th September
'S'	7.58	26th September
3rd T.L. 'M'	3.82	19th September
'S'	7.66	26th September
P.L. 'S'	5.71	22nd September
Position 'M'	3.84	19th September
Position 'S'	6.34	24th September

From Table 207 it can be concluded that the mean time of flowering, for flowers on the main axis ('M' position) is the 19th September; and for flowers on secondary branches ('S' position) is the 24th September, and these dates will be used to calculate the age of seed from different positions.

Plant Growth, Number of Pods and Number of Seeds Per Plant

Table 208 shows the stem dry matter, the number of pods per plant and the number of seeds per plant. From the analysis of variance it was found that none of these parameters was affected by the harvest stage.

TABLE 208 : The Influence of Harvest Stage on Stem Dry Matter, Number of Pods and Number of Seeds Per Plant

Harvest Stage	Means of 16 Plants		
	Stem Dry Matter (g)	Pods Per Plant	Seeds Per Plant
1st	5.10	12.44	50.00
2nd	4.17	11.37	45.07
3rd	4.09	12.31	50.00
4th	4.02	12.12	45.62
5th	4.11	12.69	47.37
6th	4.16	12.00	47.82
7th	3.82	12.56	49.75
8th	4.21	13.87	53.87
5% LSD	1.03	1.91	7.78

Number of Seeds Per Pod

It was found that the number of seeds per pod was significantly affected by the pod position on the plant only at 1% level.
In Table 209, where the number of seeds per pod are given, it can be seen that pods from the main axis contained more seeds than pods from the secondary branches.

TABLE 209 : The Influence of Harvest Stages and Pod Position (Main effects) on Number of Seeds Per Pod

Harvest Stage	Means of 8 Plants Seeds/Pod	Pod Position	Means of 32 Plants Seeds/Pod
1st	3.93 a	M	4.31 a
2nd	3.77 a	S	3.25 b
3rd	3.82 a		
4th	3.62 a		
5th	3.67 a		
6th	3.86 a		
7th	3.77 a		
8th	3.83 a		
5% LSD	0.44		0.22

Data followed by different letters (a,b) within a column are significantly different.

Seed Yield

The seed yield was significantly affected at 1% level of significance by the harvest stages.

In Table 210 the seed yield per plant and per harvest stage is given. From this table it can be seen that higher seed yield was obtained with late harvests (8th, 7th, 6th) and lower with early (1st, 2nd).

TABLE 210 : The Influence of Harvest Stages (Main effects) on Seed Yield Per Plant

Harvest Stage	Means of 16 Plants Seed Yield/Plant (g)
1st	15.22 d
2nd	16.52 cd
3rd	19.90 ab
4th	18.42 bc
5th	19.10 bc
6th	19.62 ab
7th	20.50 ab
8th	21.82 a
5% LSD	3.71

Data followed by different letters (a-d) are significantly different.

Table 211 shows the seed yield distribution, in percentages, on the two different positions (main axis and secondary branches). It can be seen that the contribution of the secondary branches in the total seed yield per plant is increasing from the early to the late harvests.

TABLE 211 : Seed Yield Distribution on the Main Axis and on the Secondary Branches

Harvest Stage	Main Axis ('M')	Secondary Branches ('S')
1st	71.77	28.23
2nd	75.60	24.40
3rd	75.08	24.92
4th	69.06	30.94
5th	63.68	36.32
6th	68.00	32.00
7th	70.62	29.38
8th	60.13	39.87

The seed moisture content at each harvest is shown in Table 212. The pods of the 40 selected plants were harvested separately for each branch and the number of pods and the pod yields per branch were recorded. From these observations the contribution of each branch to the total pod yield was found and from the number of flowers and number of pods per branch the percentage of setting in each branch was calculated (Table 213). From Table 213 it can be seen that most of the pods were produced on the top of the main axis and on the primary leaves. The setting was better in flowers at the top of the main axis and of the 2nd and 3rd trifoliate leaves ('M' position).

TABLE 212 : Seed Moisture Content Per Pod Position and Per Harvest Stage, as Percentage of Fresh Weight

Harvest Stage	Main Axis ('M')	Secondary Branches ('S)
1st	59.28	63.41
2nd	55.92	59.94
3rd	50.26	53.49
4th	22.27	49.80
5th	16.31	21.90
6th	14.79	16.19
7th	11.25	14.34
8th	11.98	15.37

TABLE 213 : Flower and Pod Distribution on a *Phaseolus vulgaris* (cultivar 'Cascade') Plant and Percentage of Setting Per Branch. T.L. = Trifoliate Leaf. P.L. = Primary Leaf.

Observation	Top		1st T.L.		2nd T.L.		3rd T.L.		P.L.
	'M'	'S'	'M'	'S'	'M'	'S'	'M'	'S'	'S'
Total No. Flowers	455	43	296	126	241	187	142	188	944
Flowers/Plant	11.37	1.07	7.40	3.15	6.02	4.67	3.55	4.70	23.60
% Flowers	17.35	1.64	11.29	4.80	9.19	7.13	5.42	7.17	36.00
Total No. Pods	128	2	59	6	65	16	62	19	146
Pods/Plant	3.2	0.05	1.47	0.15	1.62	0.40	1.55	0.47	3.65
% Pods	25.45	0.40	11.73	1.19	12.92	3.18	12.33	3.78	29.03
% Setting	28.13	4.65	19.93	4.76	26.97	8.56	43.66	10.11	15.47
Total Pod Yield (g)	459.30	7.18	203.94	24.64	295.53	66.94	265.84	61.51	554.97
Pod Yield/Plant (g)	11.48	0.18	5.10	0.62	7.39	1.67	6.65	1.54	13.87
% Pod Yield	23.68	0.37	10.51	1.27	15.23	3.45	13.70	3.17	28.61

Seed to Empty Pod Ratio (S:EP)

From the analysis of variance it was found that the S:EP ratio was significantly affected by the pod position only at 5% level of significance.

Table 214 gives the S:EP ratio values as they were affected by the harvest stages and the pod position (main effects). It can be seen that the worst ratio was achieved in pods from the 'S' position.

TABLE 214 : The Influence of Harvest Stages and Pod Position (Main effects) on S:EP Ratio

Harvest Stage	Means of 8 Plants S:EP Ratio	Pod Position	Means of 32 Plants S:EP Ratio
1st	2.694 a	M	3.062 a
2nd	2.927 a	S	2.897 b
3rd	3.039 a		
4th	2.930 a		
5th	3.060 a		
6th	3.046 a		
7th	3.047 a		
8th	3.095 a		
5% LSD	0.281		0.140

Data followed by different letters (a,b) within a column are significantly different.

Seed Size Determination

(a) Weight of Individual Seeds

The mean seed weight has been calculated as in previous experiments. From the analysis of variance it was found that this was significantly affected by the harvest stages and by the interaction harvest stages x pod position, both at 1% level. Tables 215 and 216 give the mean seed weight per harvest stage and pod position. It can be observed that the heaviest seeds were produced with the middle and late harvests (4th-8th) and the lightest with the 1st harvest.

TABLE 215 : The Influence of Harvest Stages (Main effect) on Individual Seed Weight and 100 Seed Weight

Harvest Stage	Means of 8 Plants	
	Individual Seed Weight (g)	100 Seed Weight (g)
1st	0.293 d	28.70 d
2nd	0.356 c	35.04 c
3rd	0.385 b	38.03 b
4th	0.406 ab	40.30 a
5th	0.406 ab	39.13 ab
6th	0.413 a	39.34 ab
7th	0.418 a	40.03 ab
8th	0.410 a	39.84 ab
5% LSD	0.025	2.09

Data followed by different letters (a-d) within a column are significantly different.

TABLE 216 : The Influence of Pod Position (Main effects) on Individual Seed Weight and 100 Seed Weight

Pod Position	Means of 32 Plants	
	Individual Seed Weight (g)	100 Seed Weight (g)
M	0.392 a	38.45 a
S	0.380 a	36.65 b
5% LSD	0.012	1.04

Data followed by different letters (a,b) within a column are significantly different.

Table 217 gives the mean seed weight due to the interaction harvest stages x pod position. Examining this table it can be seen that heavier seeds were produced on the main axis from the 3rd up to the 7th harvest and on the secondary branches from the 4th up to the 8th harvest. A decline in seed weight can be observed in seed from the main axis harvested at the 8th stage.

TABLE 217 : The Influence of the Interaction Harvest Stages x Pod Position on Individual Seed Weight

Harvest Stage	Means of 4 Plants (g)	
	Pod Position	
	Main Axis (M)	Secondary Branches (S)
1st	0.327 f	0.258 g
2nd	0.380 cd	0.331 ef
3rd	0.405 abc	0.365 de
4th	0.405 abc	0.408 abc
5th	0.403 abc	0.409 abc
6th	0.413 abc	0.414 abc
7th	0.405 abc	0.431 a
8th	0.394 bcd	0.425 ab

5% LSD : 0.035

Data followed by different letters (a-g) are significantly different.

(b) 100 Seed Weight

The analysis of variance showed similar results with those in the individual seed weight. The 100 seed weight was significantly affected by the harvest stages, by the pod position and by the interaction harvest stages x pod position, all at 1% level of significance. Tables 215 and 216 give the 100 seed weight due to the harvest stage and pod position main effects. It can be seen that the heaviest seeds were produced from the 4th harvest up to the 8th, and seeds in the 'M' position were heavier than seeds in the 'S' position. Table 218 gives the 100 seed weight due to the interaction between harvest stages and pod position. It can be observed that heavier seeds were produced on the main axis from the 3rd up to the 8th harvest and on the secondary branches from the 4th up to the 8th harvest.

TABLE 218 : The Influence of the Interaction Harvest Stage x Pod Position on 100 Seed Weight

Harvest Stage	Means of 4 Plants (g)	
	Pod Position	
	Main Axis (M)	Secondary Branches (S)
1st	32.35 e	25.06 f
2nd	37.29 bc	32.79 de
3rd	40.39 a	35.67 cd
4th	40.16 ab	40.44 a
5th	38.66 ab	39.60 ab
6th	40.14 ab	38.54 abc
7th	39.89 ab	40.17 ab
8th	38.75 ab	40.93 a

5% LSD = 2.95

Data followed by different letters (a-f) are significantly different.

Germination Test

(a) Germination Percentage

The germination percentages were transformed into angles and then statistically analysed. From the analysis of variance it was found that the percentage of germination was significantly affected by the harvest stage at 1% level and by the pod position at 5% level.

Tables 219 and 220 give these percentages due to the harvest stage and pod position main effects. It can be seen that the 1st harvest produced seed with the highest germination percentage. From the 2nd harvest up to the 8th harvest the germination showed a slight but significant decline. Also seeds from the 'M' position germinated better than seeds from the 'S' position.

(b) Germination Rate

The germination rate was significantly affected by the harvest stage only at 5% level. Tables 219 and 220 show that the highest rate was achieved in seed from the 1st harvest. There is a slight but significant decline in seed from the 2nd harvest up to the 6th harvest and then a slight increase. Seeds from different positions on the plant had similar germination rates.

TABLE 219 : The Influence of Harvest Stages (Main effect) on Germination Percentage, Germination Rate and Seedling Dry Weight

Harvest Stage	Means of 6 Plants			
	Germination Percentage		Germination Rate	Seedling Dry Weight (g)
	Angles	%		
1st	88.1 a	99.89	14.92 a	0.107 c
2nd	80.4 ab	97.19	14.31 abc	0.117 b
3rd	76.4 b	94.49	14.52 ab	0.123 ab
4th	80.6 ab	97.33	13.89 c	0.118 ab
5th	73.1 bc	91.55	14.25 bc	0.120 ab
6th	76.5 bcd	94.55	13.84 c	0.124 a
7th	66.4 c	83.97	14.06 bc	0.124 a
8th	73.9 bc	92.31	14.23 bc	0.124 a
5% LSD	7.8		0.61	0.007

Data followed by different letters (a-e) within a column are significantly different.

TABLE 220 : The Influence of Pod Position (Main effect) on Germination Percentage, Germination Rate and Seedling Dry Weight

Pod Position	Means of 24 Plants			
	Germination Percentage		Germination Rate	Seedling Dry Weight (g)
	Angles	%		
M	79.9 a	96.91	14.27 a	0.124 a
S	73.9 b	92.34	14.23 a	0.115 b
5% LSD	3.90		0.30	0.003

Data followed by different letters (a,b) within a column are significantly different.

(c) Seedling Dry Weight

The seedling dry weight was significantly affected by the harvest stage at 1% level, by the pod position at 1% level and by the interaction harvest stage x pod position at 5% level. The main effects of harvest stages and pod position are given in Tables 219 & 220, which show that the heaviest seedlings were produced from seed harvested at the 6th, 7th and 8th harvests, followed by seeds harvested at the 3rd, 4th and 5th harvests. Seeds from the 'M' position produced heavier seedlings than seed from the 'S' position. The seedling dry weight due to the interaction harvest stages x pod position are given in Table 221. It can be seen that the heaviest seedlings were produced from seed on the main axis harvested from the 3rd up to the 7th harvest and on the secondary branches harvested at the 8th harvest. The lightest seedlings were produced from seed harvested at the 1st and 2nd stages and from the secondary branches.

TABLE 221 : The Influence of the Interaction Harvest Stage x Pod Position on Seedling Dry Weight

Harvest Stage	Means of 3 Plants (g)	
	Pod Position	
	Main Axis (M)	Secondary Branches (S)
1st	0.117 def	0.097 g
2nd	0.120 bcdef	0.114 ef
3rd	0.129 ab	0.118 def
4th	0.125 abcd	0.112 f
5th	0.123 abcde	0.117 def
6th	0.129 ab	0.118 def
7th	0,130 a	0.119 cdef
8th	0.120 bcdef	0.128 abc

5% LSD : 0.010

Data followed by different letters (a-g) are significantly different.

Seedling Evaluation Test

(a) Emergence Percentage

The emergence percentage was not significantly affected by the harvest stages and pod position. These percentages are given in Tables 222 and 223.

(b) Emergence Rate

From the analysis of variance it was found that the harvest stages significantly affected the emergence rate at 1% level of significance. Tables 222 and 223 give the values of this rate, and it can be observed that the highest emergence rate was achieved in seeds from the 1st harvest. Seeds from all the other harvests gave similar results.

(c) Seedling Dry Weight

The seedling dry weight was not significantly affected by the harvest stages and pod position. These weights are given in Tables 222 and 223.

TABLE 222 : The Influence of Harvest Stage (Main effect) on Emergence Percentage, Emergence Rate and Seedling Dry Weight

Harvest Stage	Means of 6 Plants			
	Emergence Percentage		Emergence Rate	Seedling Dry Weight (g)
	Angles	%		
1st	87.3 a	99.77	11.66 a	0.311 a
2nd	82.8 a	98.42	11.30 b	0.347 a
3rd	81.9 a	98.04	11.25 b	0.355 a
4th	80.0 a	97.01	11.25 b	0.371 a
5th	78.1 a	96.76	11.11 b	0.344 a
6th	75.1 a	93.35	11.21 b	0.352 a
7th	77.9 a	95.60	11.26 b	0.367 a
8th	77.3 a	95.16	11.08 b	0.347 a
5% LSD	8.80		0.24	0.038

Data followed by different letters (a,b) within a column are significantly different.

TABLE 223 : The Influence of Pod Position (Main effect) on Emergence Percentage, Emergence Rate and Seedling Dry Weight

Pod Position	Means of 24 Plants			
	Emergence Percentage		Emergence Rate	Seedling Dry Weight (g)
	Angles	%		
M	81.9 a	98.03	11.21 a	0.347 a
S	78.2 a	95.79	11.32 a	0.352 a
5% LSD	4.40		0.12	0.019

Data followed by different letters (a,b) within a column are significantly different.

(d) Percentage of Very Weak Seedlings

From the analysis of variance it was found that these percentages were significantly affected by the pod position only at the 5% level.of significance. Tables 224 and 225 give the percentages of very weak seedlings as affected by the main effects of harvest stage and pod position. It can be seen that seeds from the 'S' position produced weaker seedlings than seeds from the 'M' position.

(e) Percentage of Weak Seedlings

These percentages were significantly affected by the interaction between harvest stages and pod position only at 5% level. Tables 224 and 225 give the percentages of weak seedlings due to the main effects and Table 226 the percentages due to the interaction between harvest stages and pod position. It can be seen from Table 226 that weaker seedlings were produced from seeds on the 'S' position, and from the early harvests (1st, 2nd, 3rd) and from seeds on the 'M' position from the 1st, 7th and 8th harvests.

(f) Percentage of Vigorous Seedlings

These percentages were significantly affected by the interaction between harvest stages and pod position only at 5% level. Tables 224 and 225 give the percentage of vigorous seedlings due to the main effects of harvest stage and pod position, and Table 227 the percentages due to the interaction between them. From this table it can be seen that the more vigorous seedlings were produced from seed on the main axis and harvested from the 2nd up to the 6th harvest; and from seed on the secondary branches and harvested from the 4th up to the 8th harvest.

TABLE 224 : The Influence of Harvest Stages (Main effects) on Percentages of Very Weak, Weak and Vigorous Seedlings

Harvest Stage	Means of 6 Plants			
	Very Weak Seedlings		Weak Seedlings %	Vigorous Seedlings %
	Angles	%		
1st	17.6 a	9.14	40.1 a	48.5 a
2nd	13.1 a	5.14	33.8 a	55.9 a
3rd	16.4 a	7.97	34.3 a	55.6 a
4th	4.8 a	0.70	35.4 a	62.5 a
5th	14.0 a	5.85	40.3 a	52.5 a
6th	18.8 a	10.38	29.5 a	58.1 a
7th	15.9 a	7.50	33.9 a	54.4 a
8th	17.7 a	9.24	39.9 a	50.2 a
5% LSD :	10.1		12.1	11.9

Data followed by different letters within a column are significantly different.

TABLE 225 : The Influence of Pod Position (Main effects) on Percentages of Very Weak, Weak and Vigorous Seedlings

Pod Position	Means of 24 Plants			
	Very Weak Seedlings		Weak Seedlings %	Vigorous Seedlings %
	Angles	%		
M	12.2b	4.47	36.3 a	56.3 a
S	17.4 a	8.94	35.5 a	32.2 a
5% LSD	5.04		6.02	5.9

Data followed by different letters (a,b) within a column are significantly different.

TABLE 226 : The Influence of the Interaction Harvest Stages x Pod Position on Percentage of Weak Seedlings

Harvest Stage	Means of 3 Plants	
	Pod Position	
	Main Axis (M)	Secondary Branches (S)
1st	40.2 abc	40.0 abc
2nd	25.6 cd	42.0 abc
3rd	28.5 bcd	40.2 abc
4th	39.0 abc	31.8 abcd
5th	35.7 abcd	44.9 ab
6th	30.0 bcd	28.9 bcd
7th	47.1 a	20.8 d
8th	44.7 ab	35.1 abcd

5% LSD : 17.07

Data followed by different letters (a-d) are significantly different.

TABLE 227 : The Influence of the Interaction Harvest Stages x Pod Position on Percentage of Vigorous Seedlings

Harvest Stage	Means of 3 Plants	
	Pod Position	
	Main Axis (M)	Secondary Branches (S)
1st	54.4 abcde	42.7 de
2nd	64.0 abc	47.8 cde
3rd	64.7 ab	46.6 de
4th	58.2 abcd	66.7 a
5th	56.9 abcde	48.2 bcde
6th	59.1 abcd	57.1 abcde
7th	51.6 abcde	57.3 abcde
8th	41.3 e	59.1 abcd

5% LSD : 16.83

Data followed by different letters (a-e) are significantly different.

Cold Test

(a) Percentage of Emergence

From the analysis of variance it was found that the seedling emergence in the cold test was significantly affected by the harvest stage only at 1% level.

Tables 228 and 229 give these percentages due to the harvest stages and pod position main effects. It can be seen that in the cold test the emergence was better in seeds harvested early rather than late. There was no significant difference in the emergence between seeds from the two different positions.

(b) Percentage of Mortality

This percentage was also significantly affected by the harvest stage only at 1% level. The mortality percentages due to the harvest stages and the pod position are given in Tables 228 and 229. It can be seen that the mortality was higher in seeds harvested later than in seeds harvested early. There was no significant difference between the mortality of seeds from the two positions.

TABLE 228 : The Influence of Harvest Stages (Main effect) on Percentages of Emergence and Mortality in Cold Test and on Electrical Conductivity

Harvest Stage	Means of 6 Plants		
	Cold Test		Electrical Conductivity (µS/g)
	% Emergence	% Mortality	
1st	60.0 a	36.7 c	57.31 c
2nd	30.7 b	68.7 b	53.03 d
3rd	26.0 bc	70.7 b	55.61 cd
4th	22.7 bc	75.3 ab	61.60 b
5th	14.0 c	85.3 a	68.01 a
6th	22.0 bc	76.0 ab	62.34 b
7th	18.0 bc	81.3 ab	62.58 b
8th	16.7 bc	81.3 ab	64.91 ab

TABLE 229 : The Influence of Pod Position (Main effect) on Percentages of Emergence and Mortality in Cold Test

Pod Position	Means of 24 Plants	
	Cold Test	
	% Emergence	% Mortality
M	25.2 a	72.8 a
S	27.3 a	71.0 a
5% LSD	7.02	6.74

Data followed by different letters within a column are significantly different.

Electrical Conductivity

From the analysis of variance it was found that the electrical conductivity was significantly affected by the harvest stages at 1% level of significance.

From Table 228 it can be seen that the highest electrical conductivity was achieved in seeds harvested at the 4th stage, followed by seeds harvested at the 8th, 7th and 6th stages. The lowest conductivity was achieved in seeds harvested at the 2nd stage.

E. DISCUSSION

1. MOTHER PLANT NUTRITION

The main purpose of this research was to study the effects of mother plant nutrition on seed yield and quality, although the study was extended to some other parameters such as plant growth, flowering, percentage of setting and earliness in flowering and maturity.

From the results given earlier, the first to be discussed are those which refer to the plant growth and development, this is followed by a discussion of effects on seed yield and quality.

Plant Growth

The plant growth was studied in Experiments 1, 2 and 3. The results of the first experiment (Table 14) indicate that only the phosphorus levels significantly affected the plant growth (measured as the length of the main axis, secondary and tertiary branches). All the other nutrients examined (nitrogen, potassium and molybdenum) produced plants with similar growth. An explanation for this can be that the selected levels of phosphorus were nearer to the deficient levels (P_1 = 0.15g P_2O_5/plant, P_2 = 0.45g P_2O_5/plant, P_3 = 0.75g P_2O_5/plant) and the selected levels for nitrogen, potassium and molybdenum were nearer to the luxury consumption levels. This can be supported by comparison of the N, P, K and Mo levels in GCRI potting compost and the experimental composts, used in the 1st experiment (Table 230).

TABLE 230 : N, P, K and Mo Content of GCRI Potting Compost and Experimental Composts, as used in the 1st Experiment

Compost	(mg/lit.)			
	N	P	K	Mo
GCRI *(Bunt, 1976)	230	120	290	0.52*
Experimental				
1st Level	100	11	83	0.52
2nd Level	200	33	166	3.00
3rd Level	300	55	249	-

Therefore, under the conditions of the 1st experiment the 3rd level of phosphorus (0.75g P_2O_5/plant) is seen to be the best for plant growth.

The results of the second experiment (Table 48) provide evidence that the plant growth, measured as stem dry matter, was significantly affected by all the nutrients examined (nitrogen, phosphorus, potassium).

In Table 231 the GCRI potting compost composition and the experimental compost composition in main nutrients are compared. It is seen that, in the experimental composts the 1st levels of N, P and K are well below and the 3rd levels well above or near to those in the GCRI potting compost. So these difference in plant growth were to some extent to be expected.

TABLE 231 : N, P and K Content in GCRI Potting Compost and Experimental Composts, as used in the 2nd Experiment

Compost	(mg/lit.)		
	N	P	K
GCRI	230	120	290
Experimental			
1st Level	50	22	41.5
2nd Level	200	87	166.0
3rd Level	350	152	290.5

On examining the main effects of nitrogen, phosphorus and potassium (Table 48) it can be concluded that the best plant growth was achieved with the 2nd and 3rd levels of nitrogen, the 3rd level of phosphorus and the 3rd level of potassium.

Not only the main effects of N, P and K, but also the interactions PK and NP significantly affected the plant growth. From Tables 49 and 50 and Figures 2 and 3 it can be seen that the 3rd level of P in combination with the 3rd level of K and the 2nd and 3rd levels of N in combination with the 3rd level of P produced plants with the best plant growth. It is concluded that under the conditions of the second experiment the best combination of the main nutrients for satisfactory plant growth is 1.2g N/plant + 2.1g P_2O_5/plant + 2.1g K_2O/plant or in a ratio 1 : 1.75 : 1.75 (N : P : K).

The N main effect on plant growth found in experiments 1 and 2 support the results of previous work made by different workers.

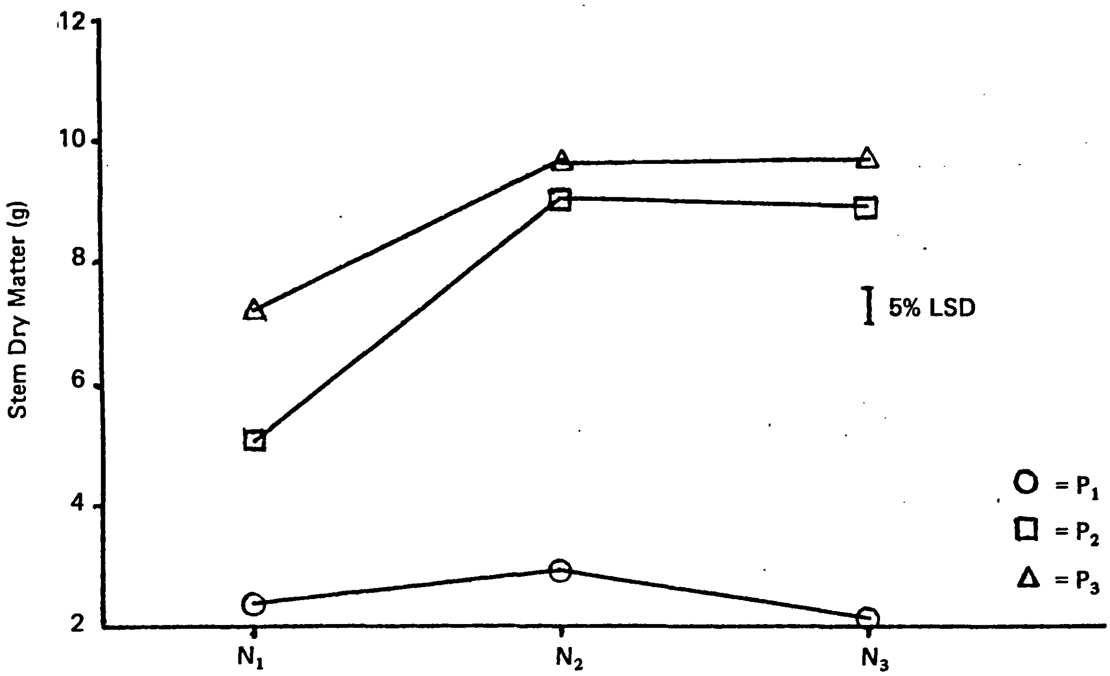

Figure 2 : Effect of NP Interaction on Stem Dry Matter (Experiment No. 2)

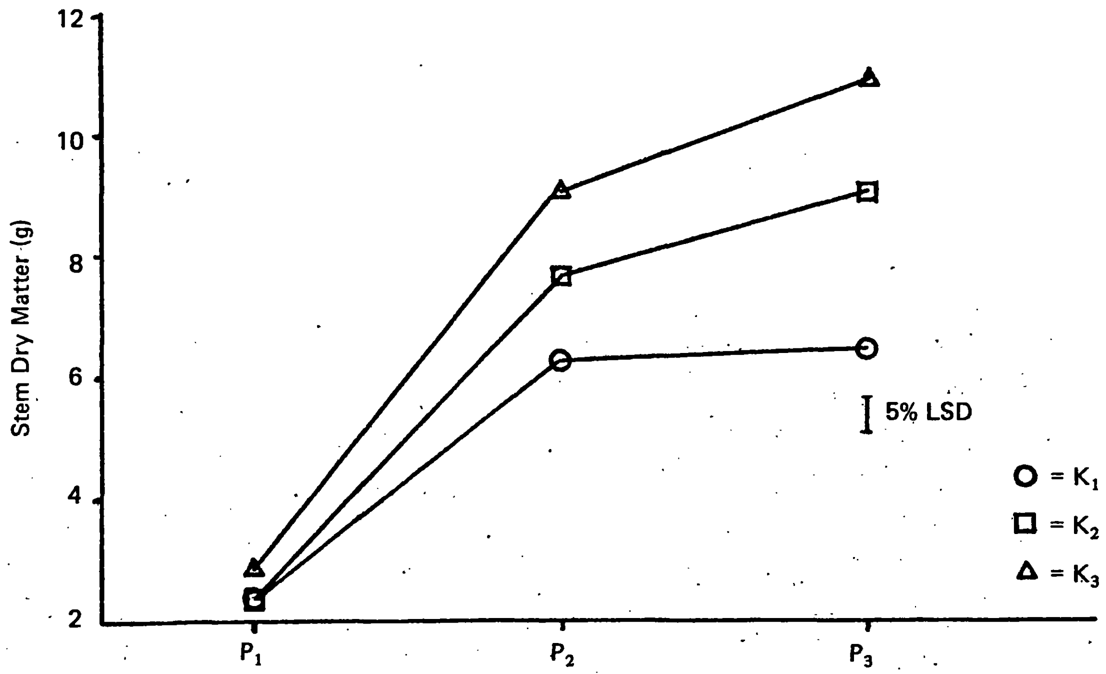

Figure 3 : Effect of PK Interaction on Stem Dry Matter (Experiment No. 2)

Edje *et al* (1975) with their work on dry beans found that dry matter production was increased with nitrogen. Splittstoesser *et al* (1974) examining the influence of nitrogen in certain vegetable crops found that fresh weight of beans, fertilized with N at 22-448 Kg/ha increased only at the highest N level. Koinov and Petkov (1975a) concluded that in general, N stimulated growth and pigment biosynthesis.

The main effects of P levels on plant growth also agree with Kanwar and Thakur's (1972) work. They found that the dry weight responses of bean plants to P and Zn were linear and that in Spring trials the plant height was depressed by the higher P levels (60 ppm).

From the other phenological observations made, during plant growth in the 2nd experiment, it can be seen that the phosphorus effect on plant growth (Plate 1) started very early during the first stages of plant development, and that the potassium effect (Plate 2) was observed later during flowering and pod development. It is known that the rate of nutrient uptake increases up to the beginning of flowering and decreases thereafter (Vitkov, 1975). These observations are in agreement with our knowledge of the role of N, P and K in plant growth and development. It is well known that nitrogen is of extreme importance to plants because it is a constituent of proteins, nucleic acids and many other important substances. Phosphorus like nitrogen is also extremely important as a structural part of many compounds, notably nucleic acids and phospholipids. In addition, phosphorus plays and indispensable role in energy metabolism. Phosphorus deficient plants develop slowly and are often stunted in growth. Potassium appears to have no structural role in plants but it serves a number of catalytic roles and is very important in the overall metabolism of plants. Many enzymes, for example several involved in protein synthesis, do not act efficiently in the absence of potassium (Bidwell, 1974).

Finally, examining the appearance of potassium deficiency symptoms it is seen that they first appeared in plants receiving the other main nutrients, and especially N, at high levels, followed later in plants receiving N at medium levels and finally in plants receiving N in lower levels. Inden, Misawa and Takei (1958) in their study of the potassium requirement of vegetable crops reported that kidney beans, along with other vegetables were markedly affected by K deficiency. They also stated that a high cation-exchange capacity of the roots tended to be associated with high sensitivity to K deficiency in Summer vegetable crops and that the reduction of K uptake by plants grown at high N levels was apparently not enhanced by the rise in root cation-exchange capacity induced by high N in such crops as legumes. Carvajal (1974) found that K and Ca uptake was closely correlated with N availability in the nutrient solution, whereas Mg and P uptake proceeded independently of N availability.

In the third experiment the plant growth was measured as dry matter of stems, as in the second experiment. The results indicate that the plant growth was significantly affected by nitrogen level, as in the second experiment, but not by molybdenum levels. Examining the nitrogen main effect it can be concluded that the 2nd and 3rd levels resulted in the best plant growth which was similar for both levels (Table 121). Taking into consideration that the other two main nutrients were added in the same concentration as in GCRI potting compost, it can be concluded that the best combination for a satisfactory plant growth is 0.90g N/plant + 1.65g P_2O_5/plant + 2.10g K_2O plant or in the N:P:K ratio of 1:1.83:2.33.

In neither Experiments 1 or 2 was a molybdenum main effect present in plant growth, although it is well known that the role of the micronutrient in nitrate reduction and nitrogen fixation is very important (Bidwell, 1974). These results support the work of Ruschel and Reuszer (1973) who found that the plant dry weight increased with increasing N and was not affected by omitting Mo from the nutrient solution.

Flower Number and Percentage of Setting

Observations on flowering and pod setting have been made only in the first experiment. It is clear that the phosphorus level significantly affected the number of flowers per plant and the percentage of setting. Plants receiving the lowest level of phosphorus (0.15g P_2O_5/plant) produced 27 flowers per plant, while plants receiving the medium level (0.45g P_2O_5/plant), i.e. 152% more than with the 1st level, and plants receiving the highest level (0.75g P_2O_5) produced 88 flowers per plant, i.e. 29% more than with the 2nd level.

The percentage of setting was found to be significantly lower (16.40%) with the 1st level of P than with the 2nd and 3rd levels (26.60% and 27.40% respectively). It seems that phosphorus in adequate quantities promoted more flower formation and better setting. The role of phosphorus is extremely important for the formation of nucleic acids and phospholipids, which in turn formulate the inherent parts of cells (MacGillivray, 1925; Bidwell, 1974).

Days to First Flower and Mean Days to Harvest

Observations for the earliness in flowering and pod maturity have been made in the 2nd and 3rd experiments.

Although in the 2nd experiment, these parameters were found to be significantly affected by the N, P and K and by some of their interactions, it can be concluded that in practice these effects are not important because their differences are less than 1 day.

Seed Yield

All the parameters related to seed yield will be discussed under this heading. These are: number of pods and number of seeds per plant, number of seeds per pod, seed yield per plant and ratio of seed : empty pod.

In the first experiment the number of pods per plant increased with increasing levels of N (Table 16) but there was no marked difference between number of pods per plant due to N_2 and N_3 levels. The pods produced from plants receiving the 2nd and 3rd levels, compared with those produced from the plants receiving the 1st level of nitrogen, increased by 8.9% and 10.5% respectively. These differences in the number of pods are reduced after setting, because no significant difference in the number of seeds per plant and per pod and in the seed yield per plant were found to result from the nitrogen levels.

In the same experiment, the number of pods and seeds per plant and seed yield per plant increased with increasing levels of phosphorus

(Tables 16, 19 and 22). Plants receiving the 2nd level of phosphorus produced 312% more pods, 339% more seeds and 345% more yield than plants receiving the 1st level of phosphorus and plants receiving the 3rd level produced 32% more pods, 34% more seeds and 35% more seed yield than plants receiving the 2nd level. It can also be observed that phosphorus had a slight effect on the number of seeds per pod (Table 21) but this effect is not important in practice as the differences are less than one seed.

In the case of pod number per plant, an interaction between N and P levels is present (Table 17 and Figure 4). From this interaction the effect of phosphorus can be confirmed, and it is concluded that the highest level of N with the highest level of P produced plants with 8.5% and 15% more pods than the combinations of N_2P_3 and N_1P_3 respectively. This effect was lost by the later stages, since this interaction is not present in the number of seeds per plant and seed yield per plant.

Potassium had a slight effect on the number of pods per plant, e.g. plants receiving the medium and high levels of K produced 8.7% and 7% more pods than plants receiving the lowest level (Table 16). However, this slight effect was covered by the plants later, as in case of nitrogen, since no K effect in the number of seeds per plant, number of seeds per pod or seed yield was found. There was no effect due to molybdenum levels on the parameters relating to seed yield. Only an interaction between nitrogen and molybdenum levels was noticeable on the number of seeds per plant and seed yield (Tables 20 and 23). Examining these interactions it can be concluded

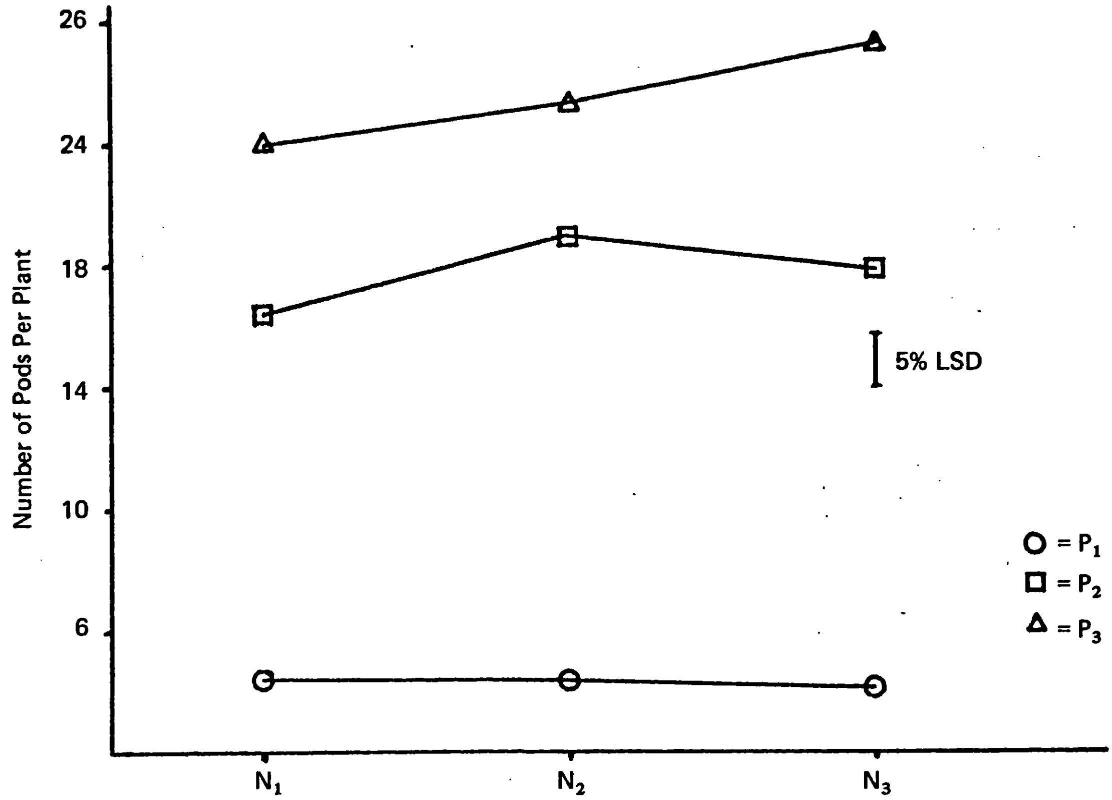

Figure 4 : Effect of NP Interaction on Number of Pods Per Plant (Experiment No. 1)

that nitrogen levels associated with the first level of molybdenum had no effect but with the second level of molybdenum there was a gradual increase in seed yield from nitrogen levels (Figures 5 and 6).

Another parameter measured and associated with the seed yield was the seed to empty pod ratio. Examining the N,P,K and Mo main effects on this ratio it can be seen that this was significantly reduced with the 2nd level of P and the 2nd and 3rd levels of K, but it was unaffected from the N levels. The differences in this ratio are more noticeable in the interactions between phosphorus and molybdenum levels (Figure 7), phosphorus and potassium levels (Figure 8) and nitrogen and potassium levels (Figure 9). The combination which gave the best ratio is $N_3P_3K_1$.

From the results mentioned above, and related to seed yield, it can be concluded that under the conditions of the 1st experiment, the highest seed yield can be achieved from plants receiving any one of N and K levels together with the highest level of P. Taking into consideration the cost of fertilizers and the observation that the lower potassium level promoted a higher ratio of seed:empty pod, the following NPK combination can be suggested:

$N_1 + P_3 + K_1$ e.g. 0.60g N + 0.75g P_2O_5 + 0.60g K_2O per plant - or 1 : 1.25 : 1 (N : P_2O_5 : K_2O).

In the second experiment the number of pods per plant increased with increasing levels of N (Table 55) but there was no marked difference in the effects due to the N_2 and N_3 levels. Thus plants receiving the 2nd and 3rd levels of N produced 32% and 27% more pods than plants receiving the 1st level.

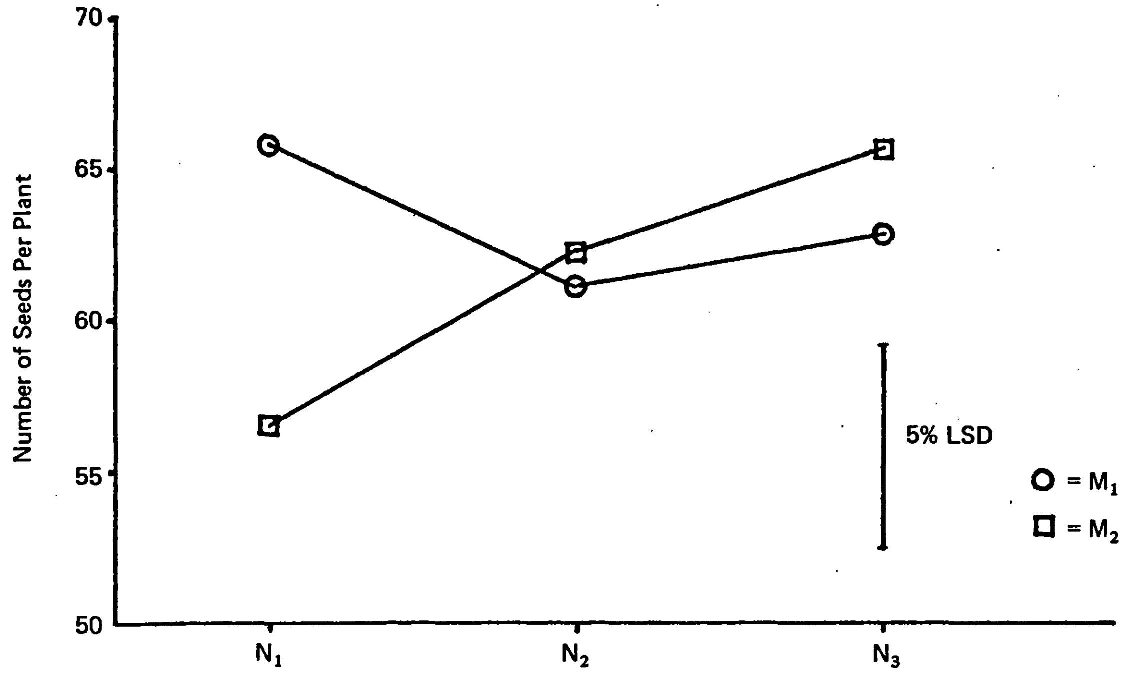

Figure 5 : Effect of N Mo Interaction on Number of Seeds Per Plant (Experiment No. 1)

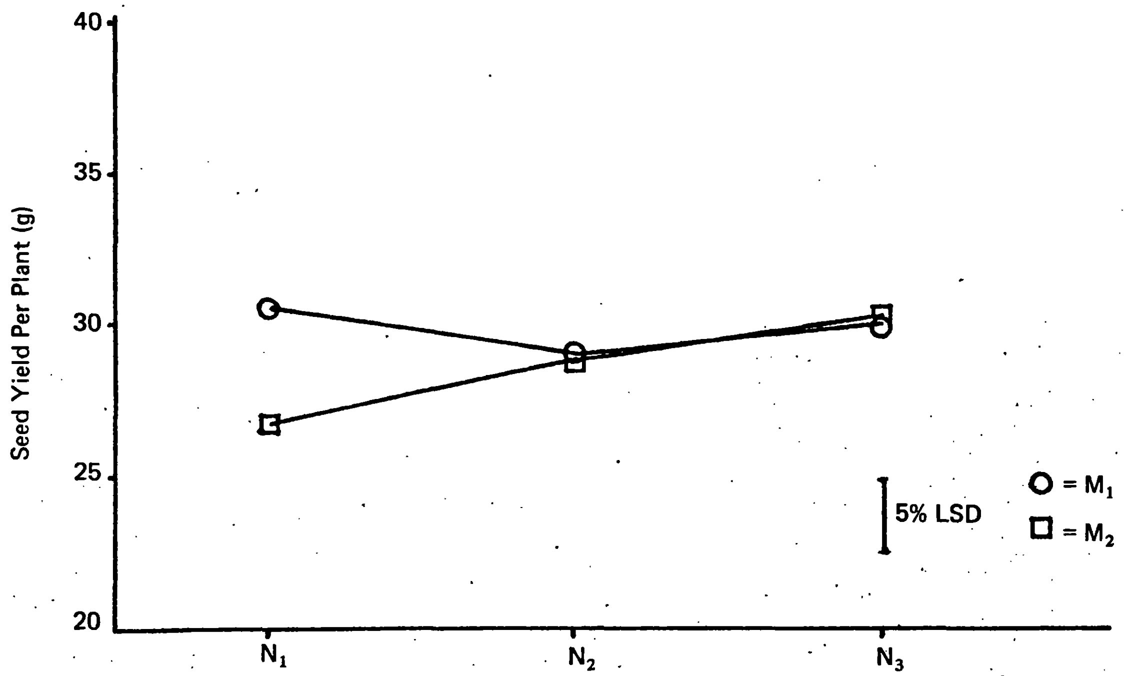

Figure 6 : Effect of N Mo Interaction on Seed Yield Per Plant (Experiment No. 1)

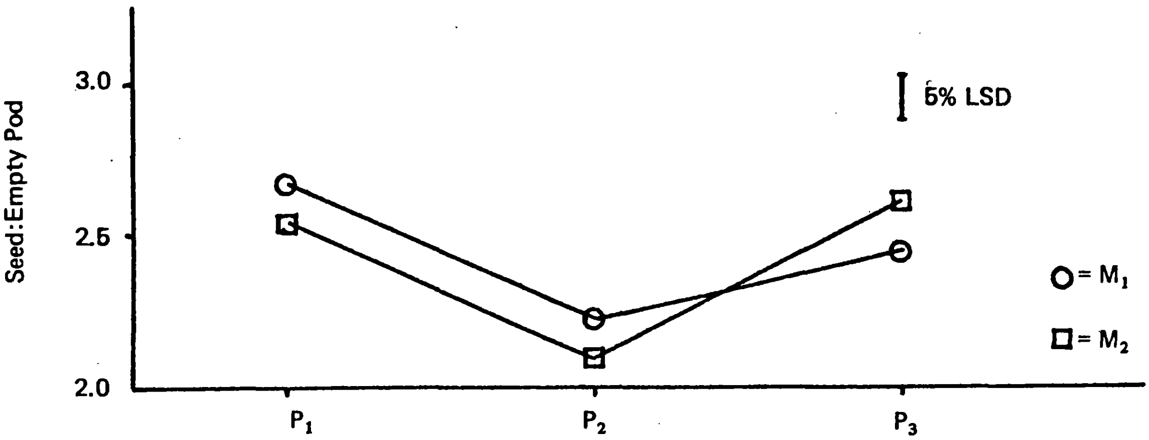

Figure 7 : Effect of P Mo Interaction on Seed:Empty Pod Ratio (Experiment No. 1).

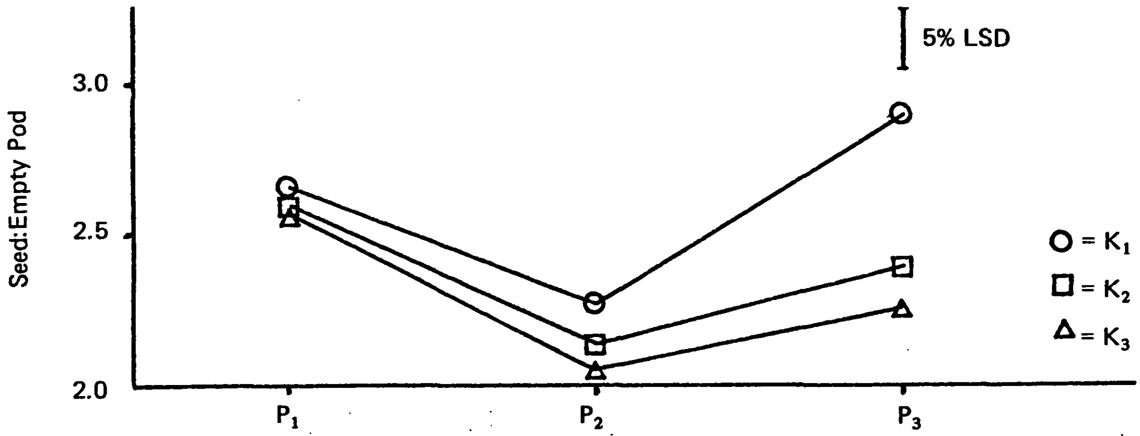

Figure 8 : Effect of PK Interaction on Seed:Empty Pod Ratio (Experiment No. 1).

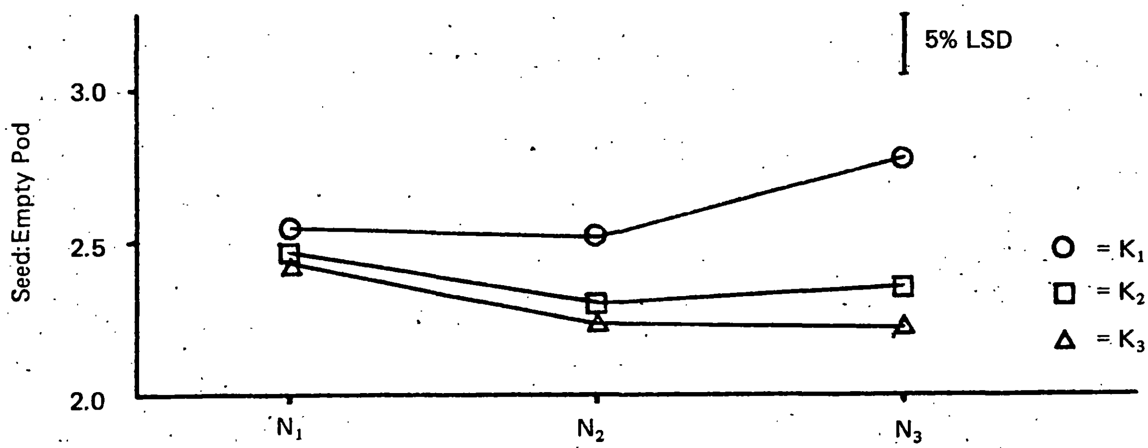

Figure 9 : Effect of NK Interaction on Seed:Empty Pod Ratio (Experiment No. 1).

The nitrogen effect continued to be present in the number of seeds per plant, but here the N_2 produced 33%, and the N_3 25% more seeds than the N_1 level (Table 60). The number of seeds per pod was unaffected from the nitrogen levels. The seed yield was affected similarly as was the number of pods per plant. Thus the 2nd level of nitrogen produced 30% and the 3rd level 26% more seed yield than the 1st level (Table 68).

Since the number of seeds per pod was the same for all the nitrogen levels it seems that the increase in the number of pods per plant is responsible for the increase in the seed yield per plant.

In the same experiment the number of pods and seeds per plant and seed yield increased with the levels of phosphorus, but the number of seeds per pod was unaffected (Tables 55, 60 and 68). Plants receiving the 2nd level of phosphorus produced 136% more pods, 138% more seeds and 136% more seed yield than plants receiving the 1st level; and plants receiving the 3rd level of phosphorus produced 9% more pods, 10% more seeds and 6% more seed yield than plants receiving the 2nd level.

In the case of the potassium main effect it can be observed that the number of pods and seeds and seed yield per plant increased with the levels of potassium (Tables 55, 60 and 68). The number of seeds per pod were slightly affected by potassium levels, especially by the 1st level, but this effect seems in practice to be unimportant, because the differences between the values are less than one, which is the minimum difference in seeds between two pods. Plants receiving the

2nd level of potassium produced 24% more pods, 44% more seeds and 53% more seed yield than plants receiving the 1st level; and plants receiving the 3rd level produced 9% more pods, 11% more seeds and 10% more seed yield than plants receiving the 2nd level of potassium.

All possible interactions between the N, P and K levels (e.g. NP, NK, PK and NPK) significantly affected the number of pods (Figures 10, 14, 18, and 20), number of seeds (Figures 11, 15, 19 and 21) and seed yield per plant (Figures 12, 16, 17 and 22). The number of seeds per pod was affected by the interactions NP and NK but these effects seem to be unimportant in practice since the differences are less than one seed per pod. Thus, the number of seeds per pod can be considered as constant for this experiment with a value of 4 seeds per pod. Examining these interactions it can be observed that the pattern of each is similar for the three parameters measured and related to seed yield. The bean plants produced more pods, more seeds and a higher seed yield as the three main nutrients increased. Although these results were observed in experiments with artificial growing media, they confirm results by Edje *et al* (1971, 1975), who found that bean yield increased with increases in N, P and K levels when grown in soil. It can also be suggested that the effect of the main nutrients on seed yield started very early, possibly at the stage of flower initiation, because the improved yields are associated with increases in the number of pods and not in the number of seeds per pod. This was also reported by Kerr (1972) from his work on beans.

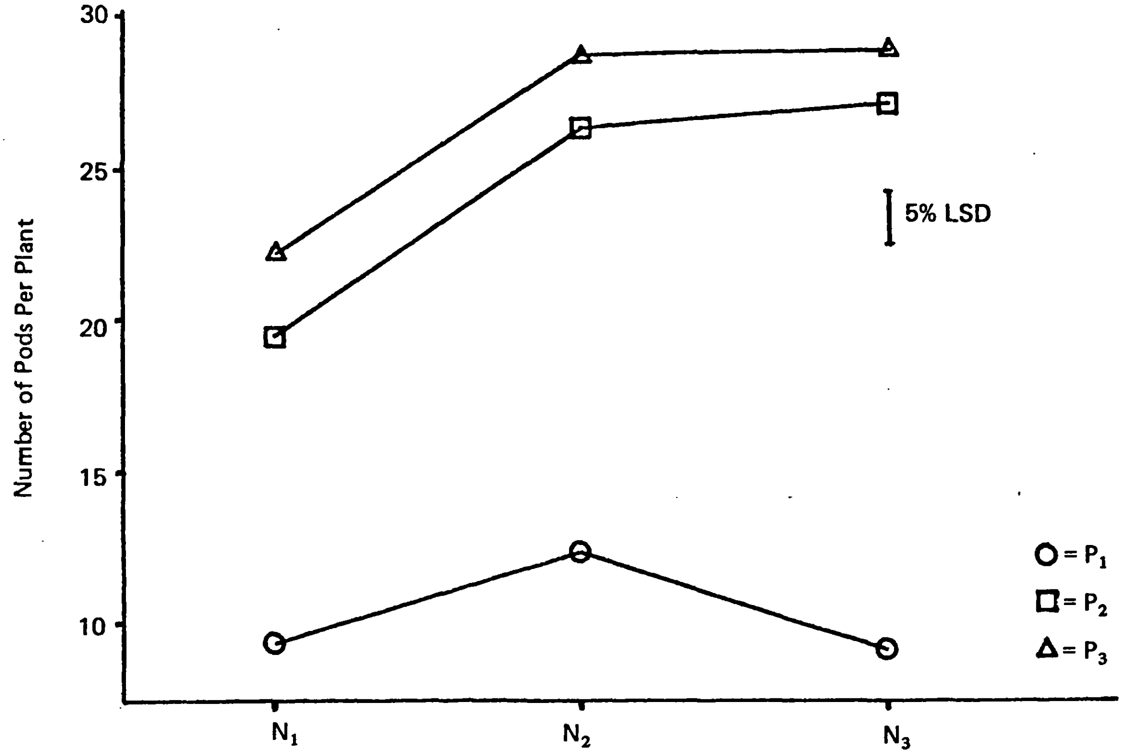

Figure 10 : Effect of NP Interaction on Number of Pods Per Plant (Experiment No. 2)

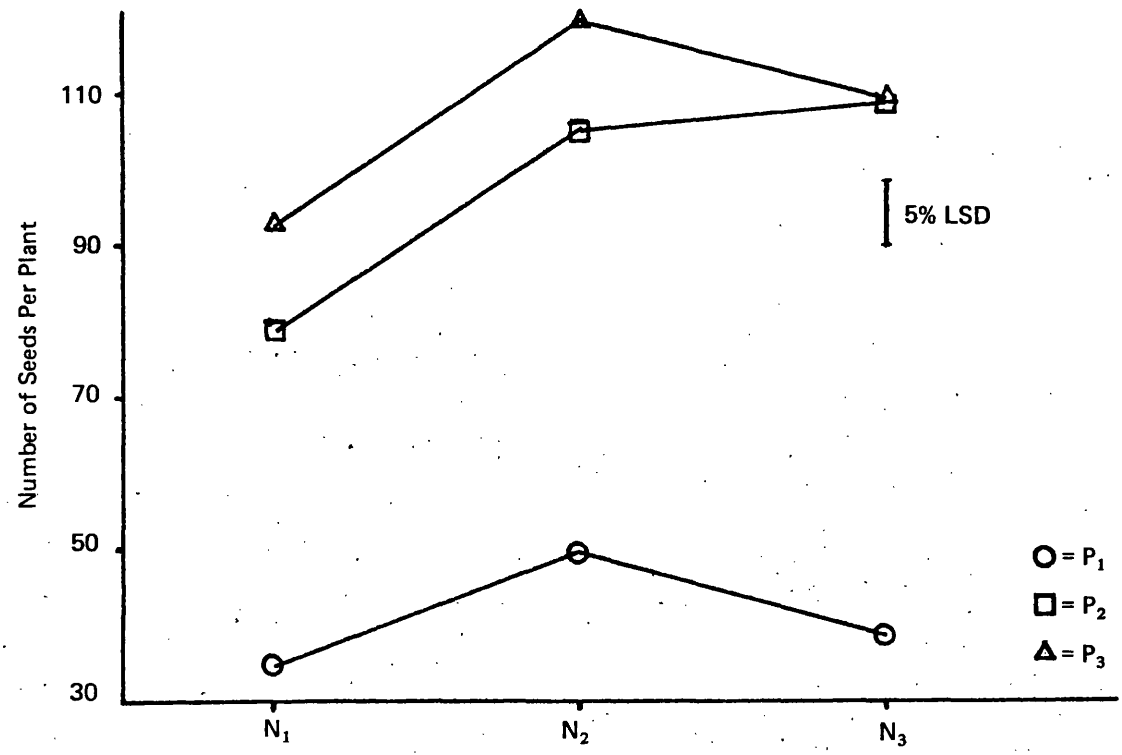

Figure 11 : Effect of NP Interaction on Number of Seeds Per Plant (Experiment No.2)

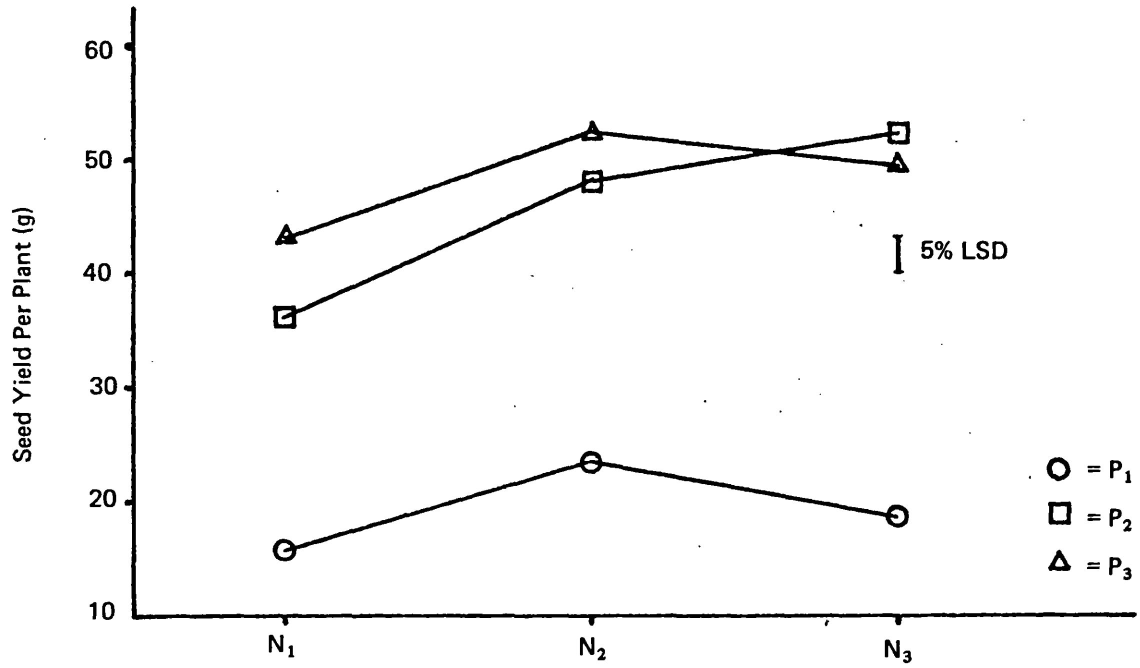

Figure 12 : Effect of NP Interaction on Seed Yield Per Plant (Experiment No. 2)

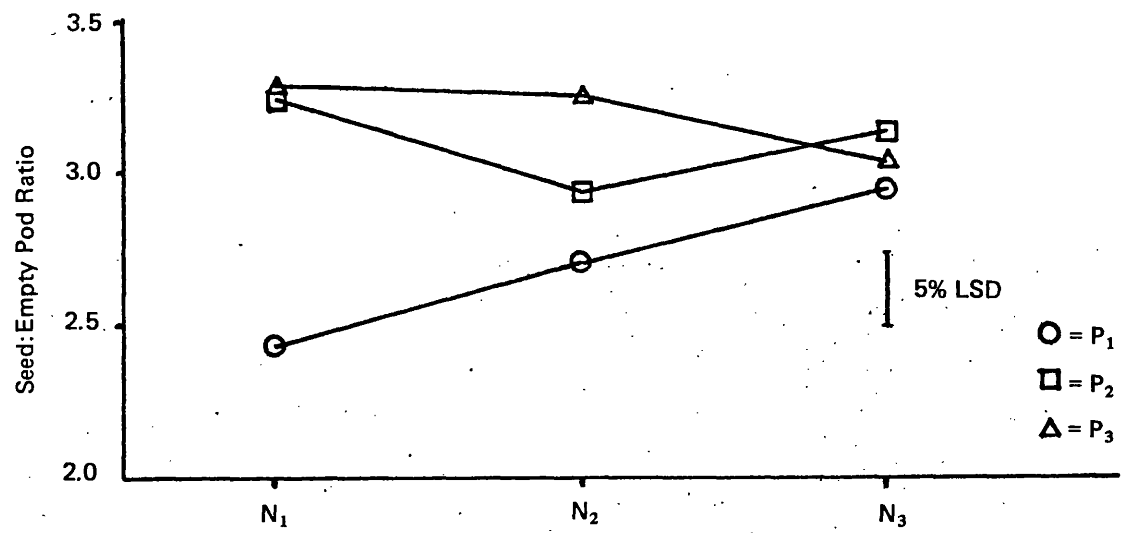

Figure 13 : Effect of NP Interaction on Seed:Empty Pod Ratio (Experiment No. 2)

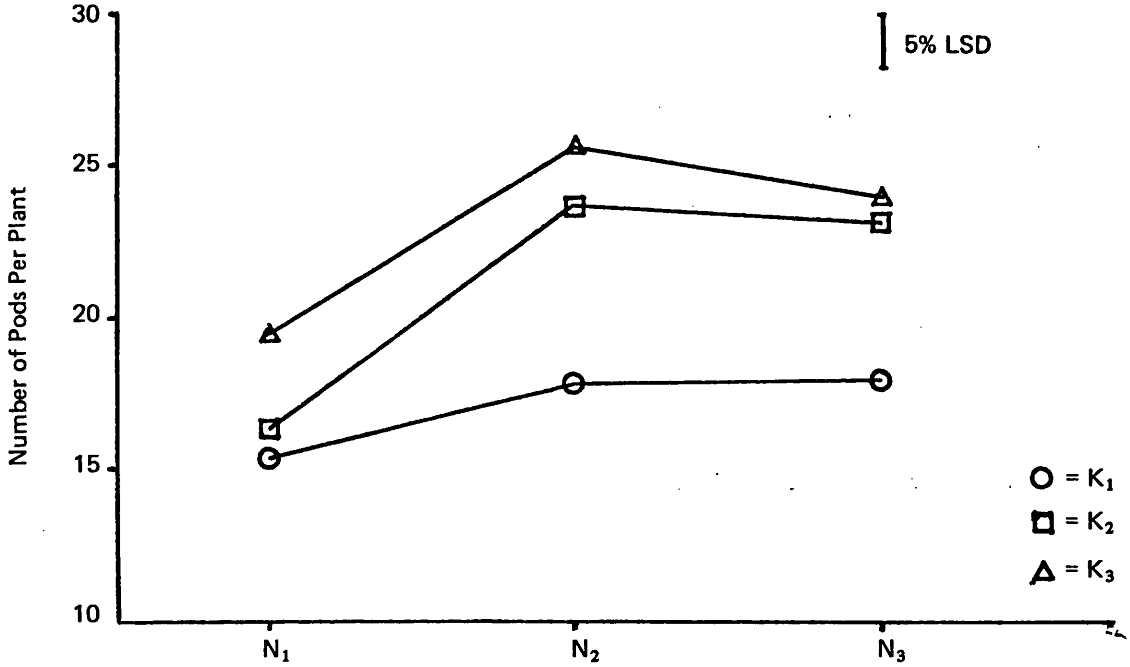

Figure 14 : Effect of NK Interaction on Number of Pods Per Plant (Experiment No. 2)

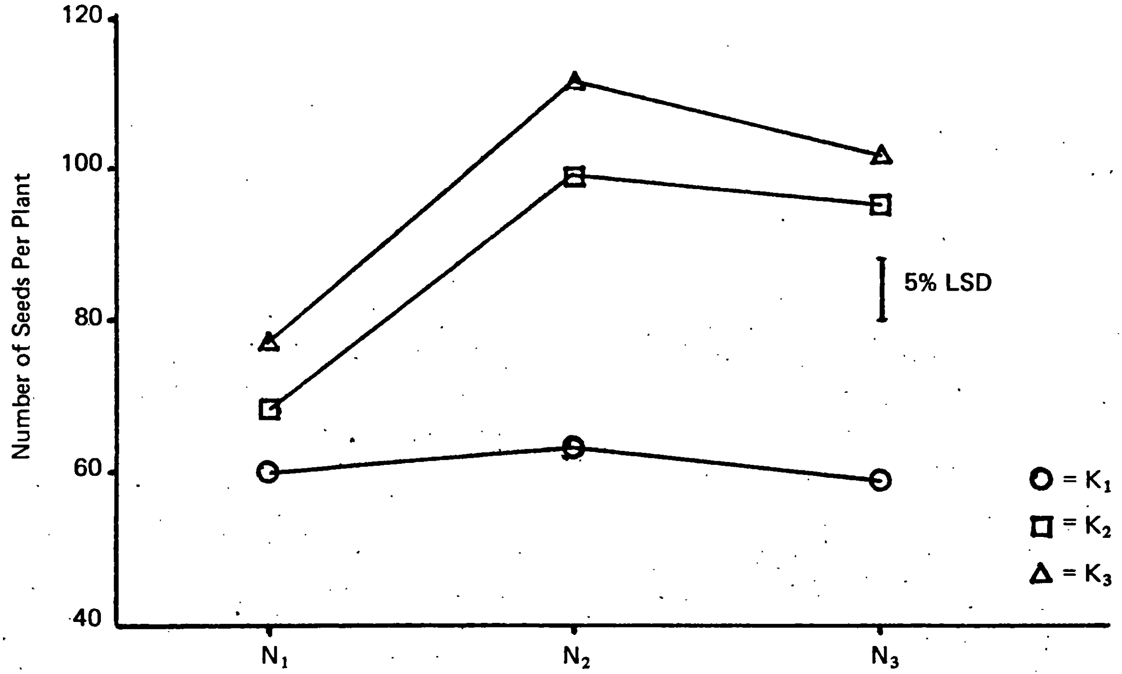

Figure 15 : Effect of NK Interaction on Number of Seeds Per Plant (Experiment No. 2)

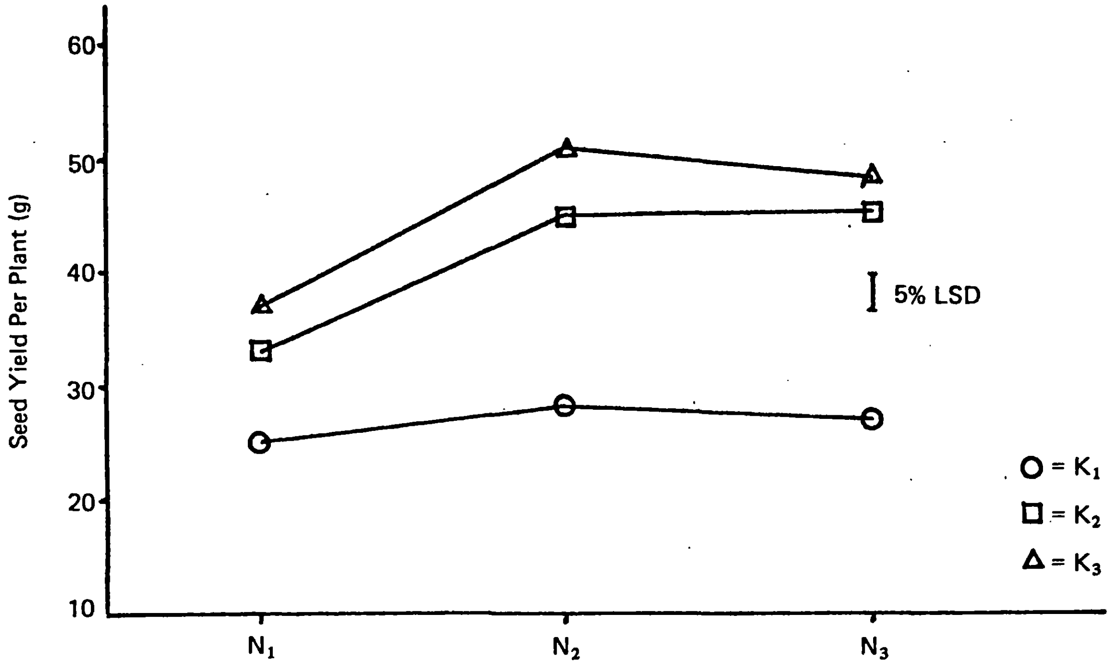

Figure 16 : Effect of NK Interaction on Seed Yield Per Plant (Experiment No. 2)

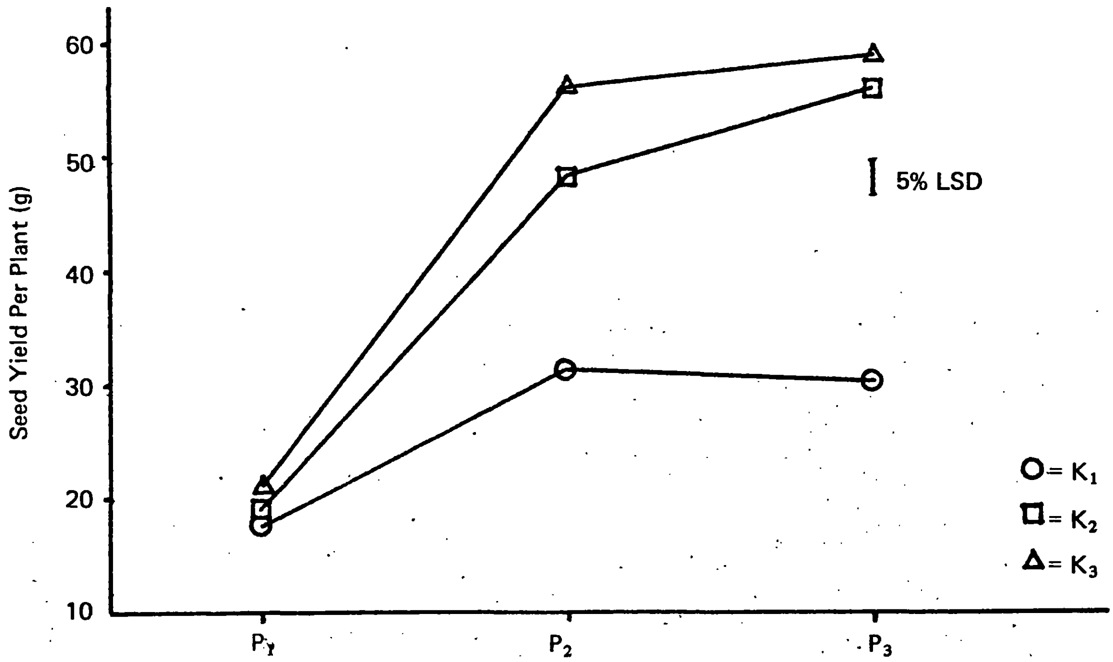

Figure 17 : Effect of PK Interaction on Seed Yield Per Plant (Experiment No. 2)

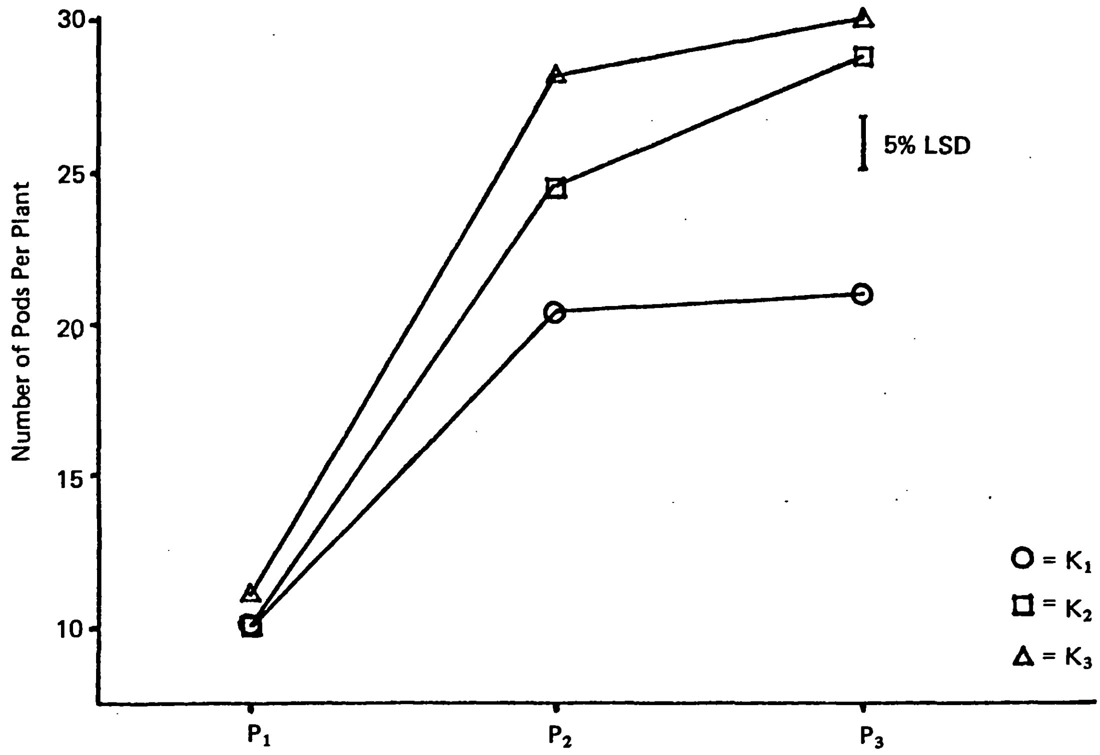

Figure 18 : Effect of PK Interaction on Number of Pods Per Plant (Experiment No. 2)

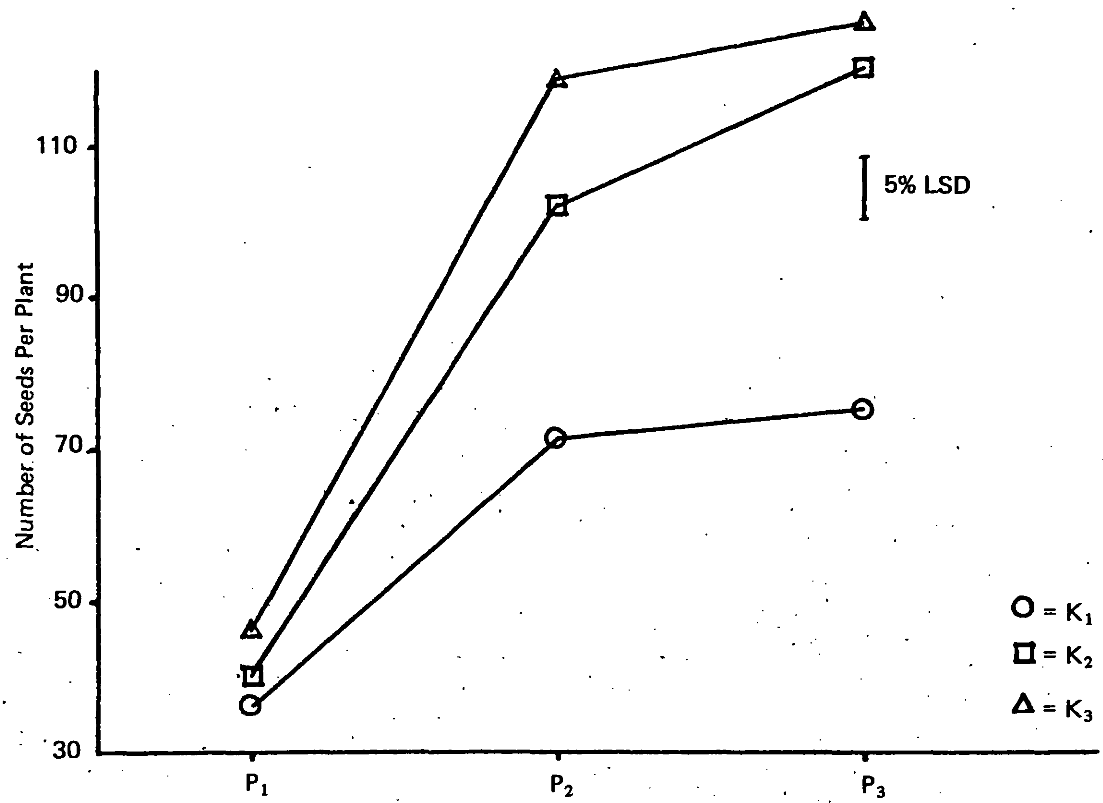

Figure 19 : Effect of PK Interaction on Number of Seeds Per Plant (Experiment No. 2)

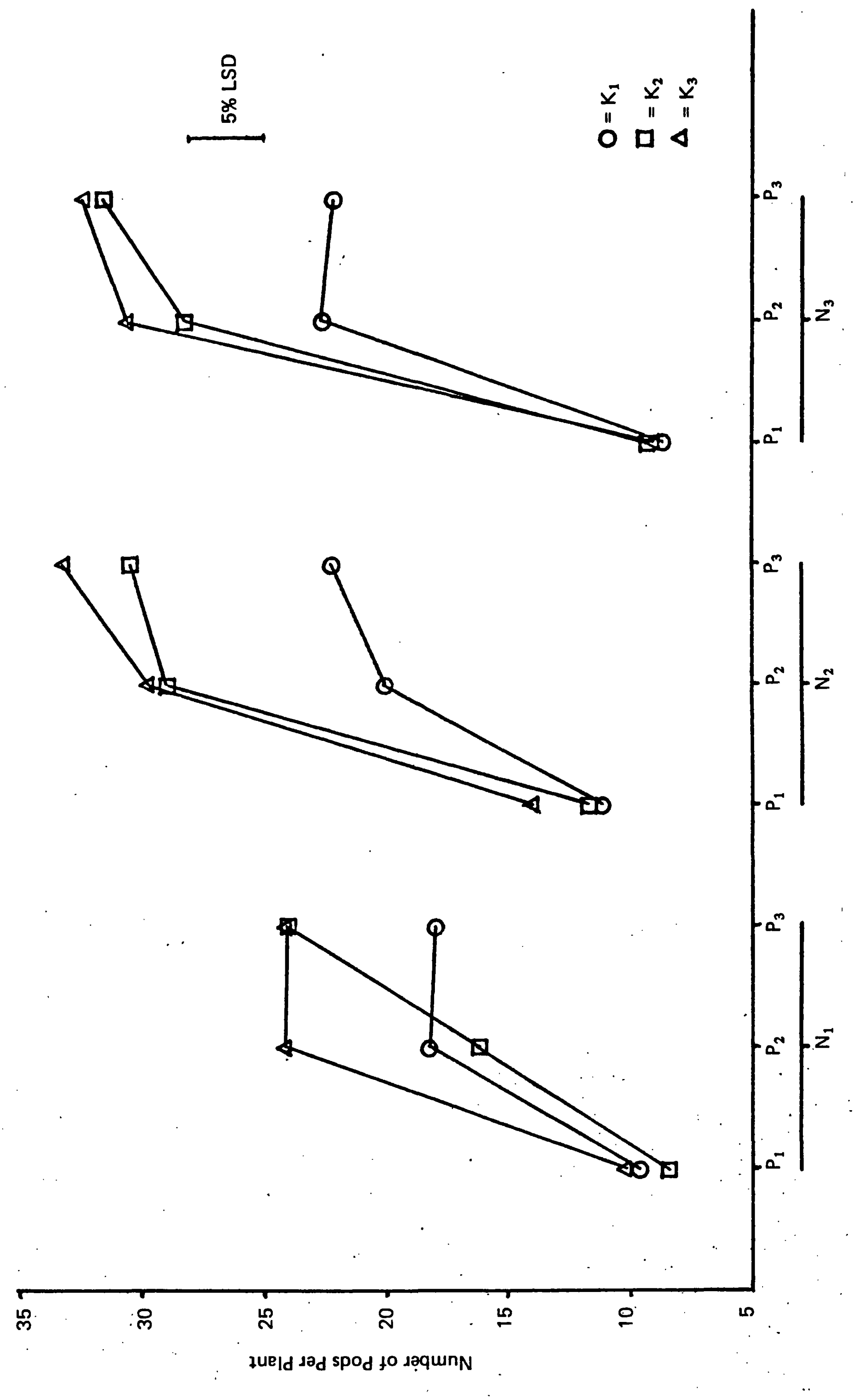

Figure 20 : Effect of NPK Interaction on Number of Pods Per Plant (Experiment No. 2)

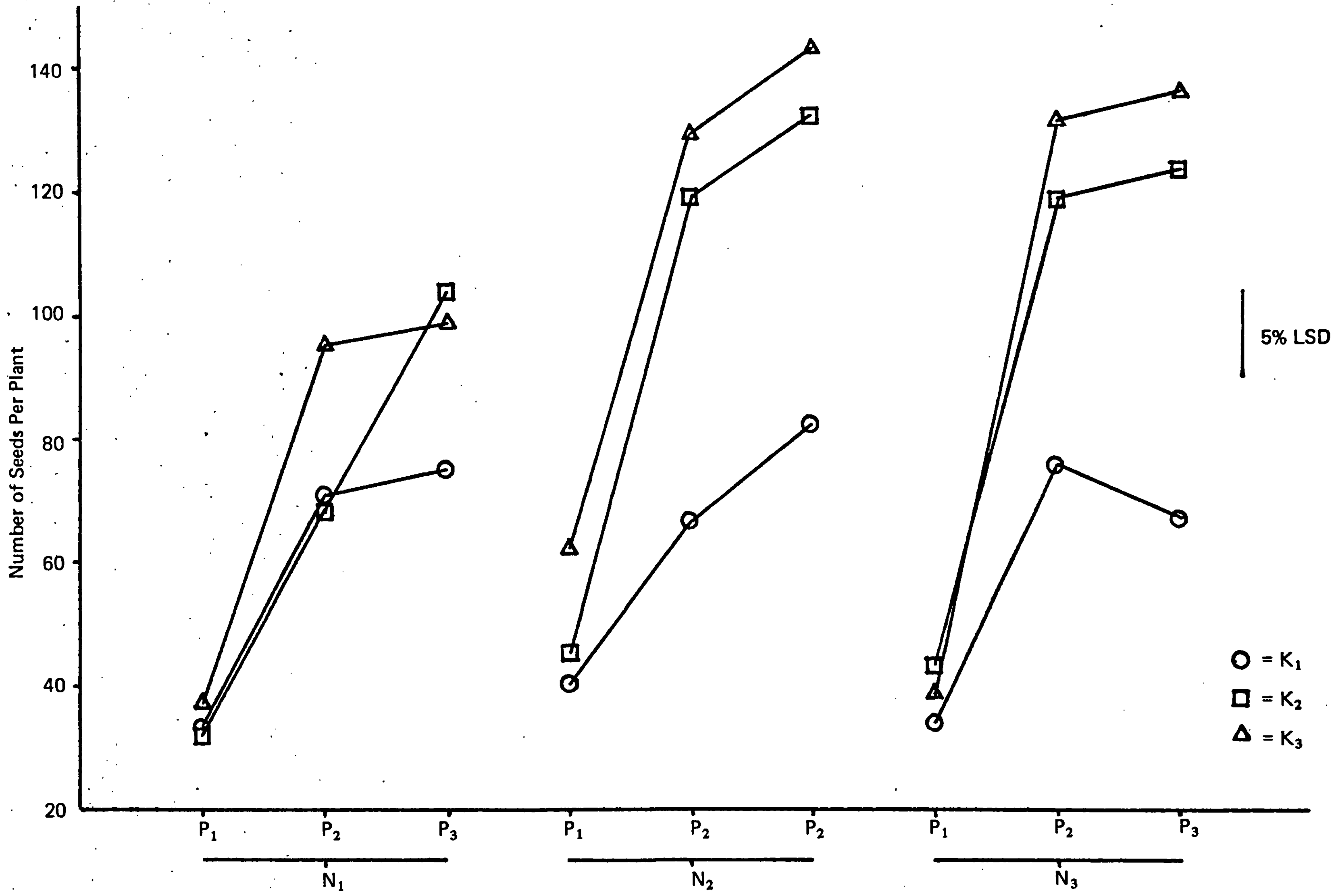

Figure 21 : Effect of NPK Interaction on Number of Seeds Per Plant (Experiment No. 2)

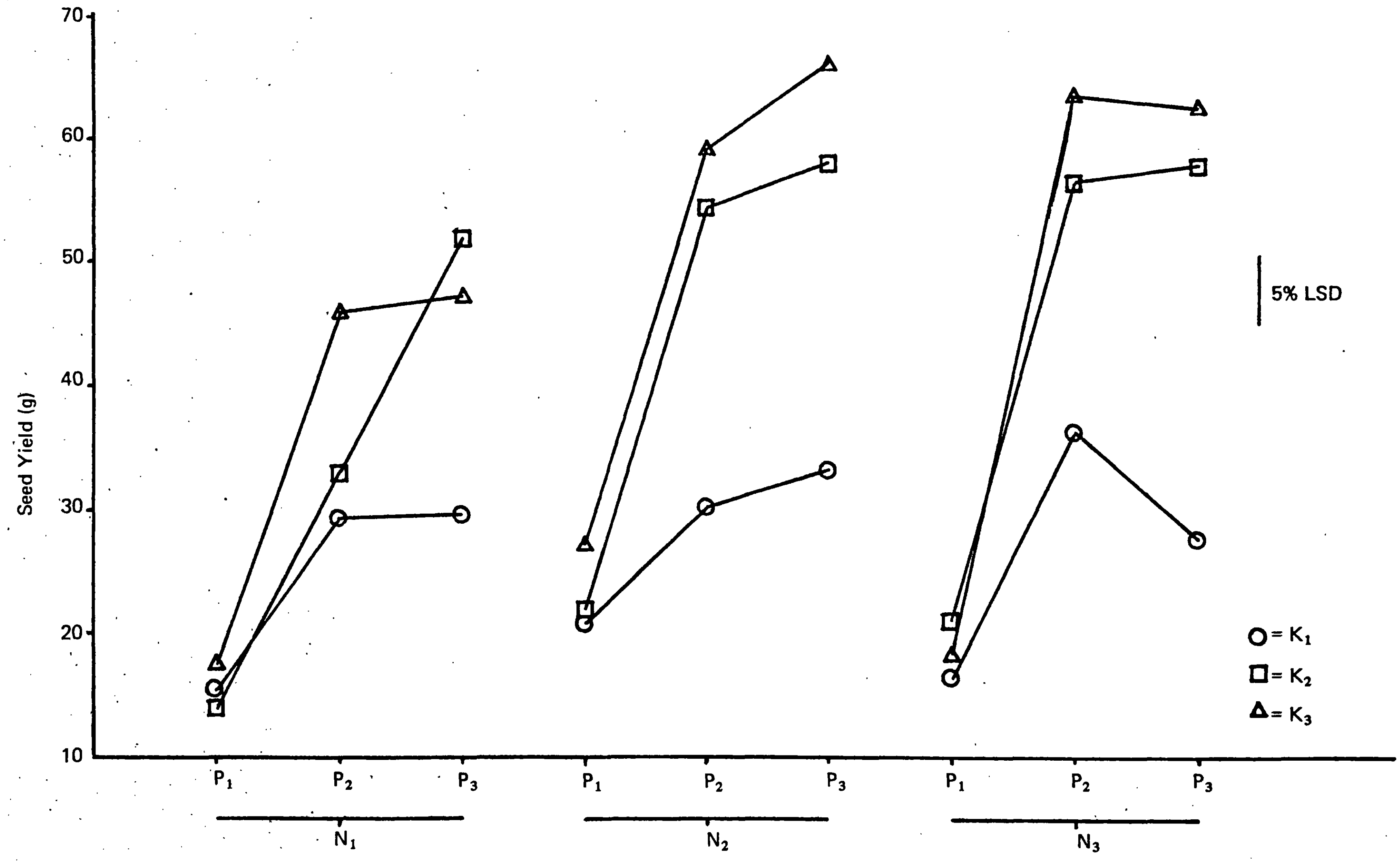

Figure 22 : Effect of NPK Interaction on Seed Yield Per Plant (Experiment No. 2)

The results from the 2nd experiment related to seed yield lead to the conclusion that the main nutrients did not act independently but interacted, and they are necessary in adequate quantities and in a balanced ratio. These quantities and ratio, under the conditions of the 2nd experiment are 1.2g N + 2.1g P_2O_5 + 2.1g K_2O/plant or 1 : 1.75 : 1.75 (N : P_2O_5 : K_2O).

Looking at the seed to pod ratio it can be seen that the results are similar to those of the 1st experiment. This ratio was not affected by the nitrogen levels and was improved by the higher levels of phosphorus and lower levels of potassium.

From the results of the 3rd experiment concerning the number of pods and seeds per plant and seed yield per plant it is observed that only the nitrogen levels significantly affected them. The number of seeds per pod was again unaffected by the nutrients examined (nitrogen and molybdenum). Plants receiving the 3rd level of N produced more pods, seeds and seed yield per plant than the other N levels did. So results of previous experiments concerning the nitrogen effect are confirmed.

Molybdenum levels, as in the 1st experiment, did not affect any of these parameters associated with seed yield, in contrast to the results of other workers who found that Mo alone or together with N, improves seed yield in beans grown in soil (Velcev and Georgiev, 1970; Nicolov, 1973; Mininberg and Le Zu, 1974). In contrast to these workers Janssen and Vitosh (1974) stated that beans grown in two acid sandy soils produced 7% lower yield when the seeds were treated with Mo. These contrasting results have been confirmed in 1970 by

Stoimenov and again in 1974. He found that seeds treated with Mo as ammonium molybdate produced a higher yield than untreated seeds, but when he repeated this Mo treatment in the subsequent generation less marked yield increases were obtained. With his second experiment with beans grown in different soils he found on leached and podzolized chernozerms that N markedly increased the yields and that Mo fertilizers gave comparable yield responses to N fertilizers. In contrast, on a calcareous chernozerm bean yields were not significantly affected by Mo and N gave inconsistent yield responses. He concluded that the combined application of N and Mo was not advantageous from a yield point of view but it had a beneficial effect on the protein content of the seed.

It is possible that the soil type (Stoimenov, 1974; Janssen and Vitosh, 1974) and the seed reserves of Mo (Meagher *et al*, 1952; Hewitt *et al*, 1954) are responsible for these contradictory results.

The results of the 4th experiment which was carried out in soil, indicate that the N levels significantly affected bean seed yield but not the P and K levels. Plots receiving the 2nd level of N (225 KgN/ha) produced 13.5% more yield than plots receiving the 1st level (150 KgN/ha). Since the quantity of the 1st N level is recommended for fresh pod production (Ministry of Agriculture, Fisheries and Food, 1973) it seems that more N is needed for bean seed production as Gallo and Miyasaka (1961) suggested.

The results of the 4th experiment concerning the seed yield agree with those found by Edje *et al* (1975). In their work they found that yield of dry beans increased with increasing levels from 0 to 200 Kg/ha.

Also they agree with Kerr's (1972) work, who concluded that the optimal economic N application was about 75-90 lb N/acre (85-100 Kg N/ha) above which further yield increases were slight, in navy bean trials. Asif and Greig (1972) examining the effects of N, P and K on yield of snap beans found that increased N application resulted in greater pod yields and that PK reduced them. Smith (1975) also noticed responses of bean yield in N and P fertilizers but he stated that the addition of K did not improve yields.

In contrast to the results mentioned above, Eira *et al* (1973) from their experiments with beans grown in the field, found that the yield responses to P were significantly linear and quadratic but they did not notice any response to N application. Almeida *et al* (1973) confirmed the results of Eira *et al* for P effects but in contrast they found significant increase in bean yield due to N. Braga *et al* (1973) growing beans in different localities examined the effects of N, P and K. They concluded that the response of bean yield to fertilizers depends on the locality. They found in most cases that the responses to N and P were positive and linear but they did not observe any response to K.

Apart from the N, P and K main effects on seed yield, in the 4th experiment an interaction between N and P levels was found to be present (Figure 23). From this interaction it can be seen that the lower level of P in combination with the higher level of N produced higher seed yield. Therefore under the conditions of the 4th experiment in the field it can be concluded that at least nitrogen and phosphorus do not act independently but interact. This partly

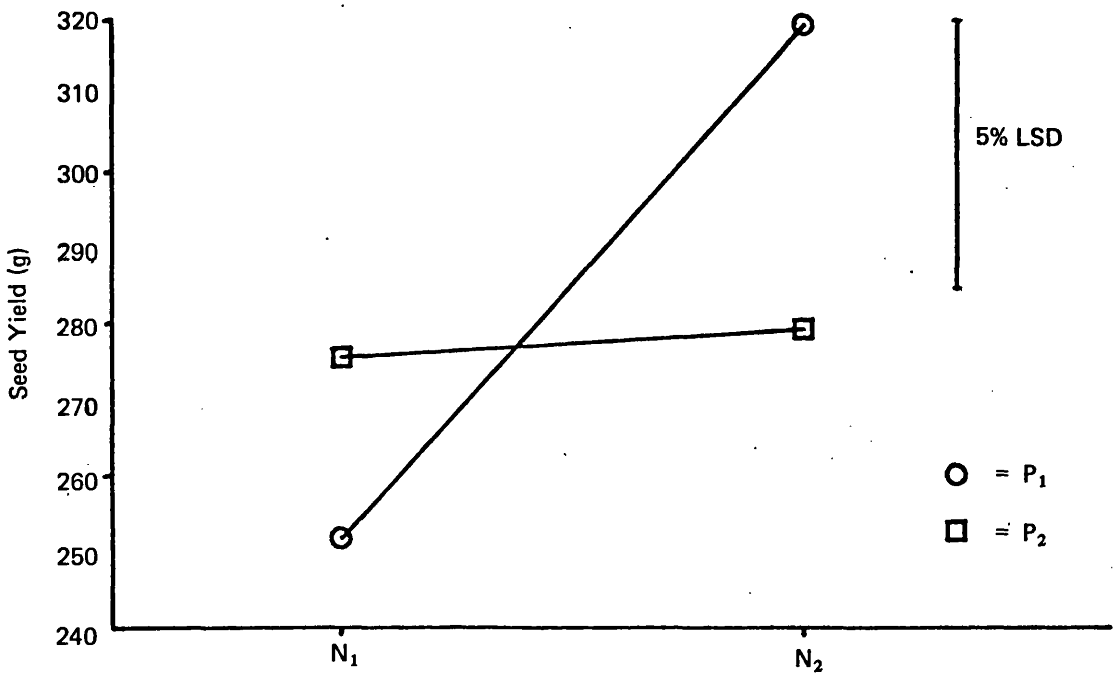

Figure 23 : Effect of NP Interaction on Seed Yield Per 50 Plants (Experiment No. 4)

confirms the interactions found in the pot experiments, where they were greater in number, and higher in order and also more noticeable, but in the field experiment the soil reserves in nutrients, especially in P and K must be taken into consideration.

Seed Quality

(a) *Seed Size*

The seed size was determined by two different methods (individual seed weight and 100 seed weight) in experiments 1, 2 and 3 and from the 100 seed weight only in the 4th experiment. From the analysis of variance in the first three experiments, it can be seen that with very few exceptions, both methods gave similar results. However, the individual seed weight was determined using all the available seed in each seed lot, which was different in each of them. Because of this and since the results from the two different methods are similar, only the 100 seed weight will be discussed.

It is very clear that nitrogen had a beneficial effect on seed size, especially in experiments 2 and 3 (Tables 80 and 130) where the 3rd level of nitrogen resulted in the heaviest seed. In experiments 1 and 4, although there was no significant effect (Tables 30 and 155) a slight increase in the 100 seed weight is observed with increase in nitrogen.

In the case of phosphorus effect, only the results of the 2nd experiment (Table 80) give evidence that this nutrient significantly affects the seed size. This effect seems to be inverse, e.g. as the phosphorus is increasing the 100 seed weight is decreasing. The heaviest seeds were produced by plants receiving the lowest levels of phosphorus.

Potassium seems not to play a very important role in seed size. Only the results of the 2nd experiment (Table 80) showed a significant effect due to potassium levels, but only the plants receiving the lowest level produced lighter seeds. The 2nd and 3rd potassium levels resulted in heavier, similar weight seeds.

The molybdenum effect was present only in the results from the 3rd experiment (Table 130). There is some evidence that the highest level slightly depressed the seed size.

In both the 1st and 2nd experiments the interaction between the main nutrients, N, P and K significantly affected the seed size (Tables 31 and 84). Combinations such as the N_3 P_2 K_1, N_1 P_3 K_1, N_2 P_3 K_2 in the 1st experiment and N_2 P_1 K_1, N_1 P_3 K_2, N_1 P_2 K_2, N_3 P_1 K_1 in the in the 2nd experiment produced the heaviest seed. On studying the graphs which present the results of these interactions (Figures 24 and 25) it can be seen that the lowest potassium levels always depress the seed size whatever the levels of the other nutrients and that the combinations of the lower levels of phosphorus with the nitrogen levels gave better results in most cases than the higher levels.

The effect of nitrogen phosphorus interaction on seed size is very clear in the results obtained from the 2nd experiment (Table 81, Figure 26). It can be seen that under low phosphorus application the increasing levels of nitrogen resulted in heavier seed, but under higher phosphorus applications the effect of nitrogen is different. The N_2 level in combination with the P_2 and P_3 levels significantly depressed the seed size, since the N_3 level in combination with P_2 and P_3 levels resulted in heavier seed.

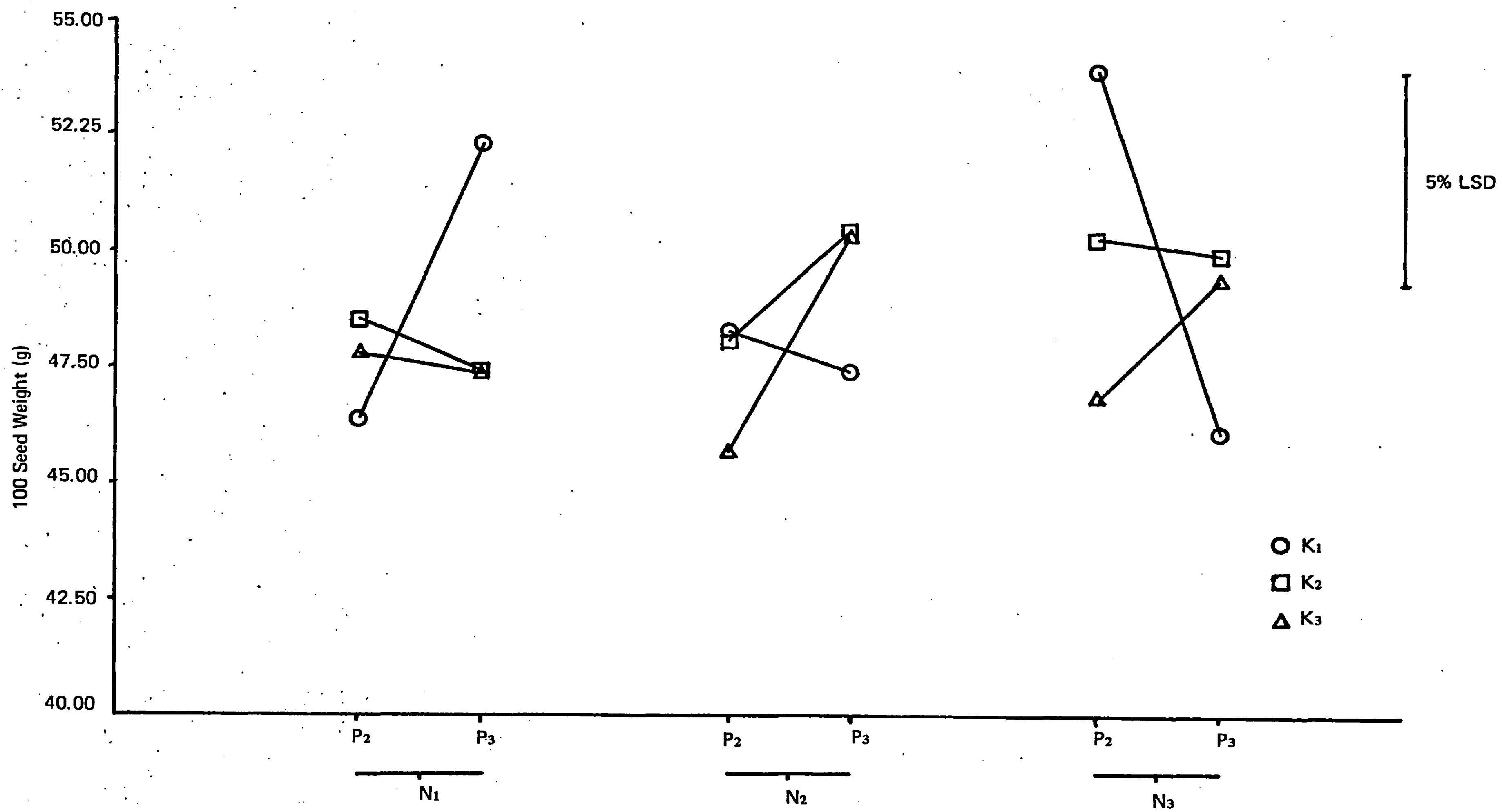

Figure 24 : Effect of NPK Interaction on 100 Seed Weight (Experiment No.1)

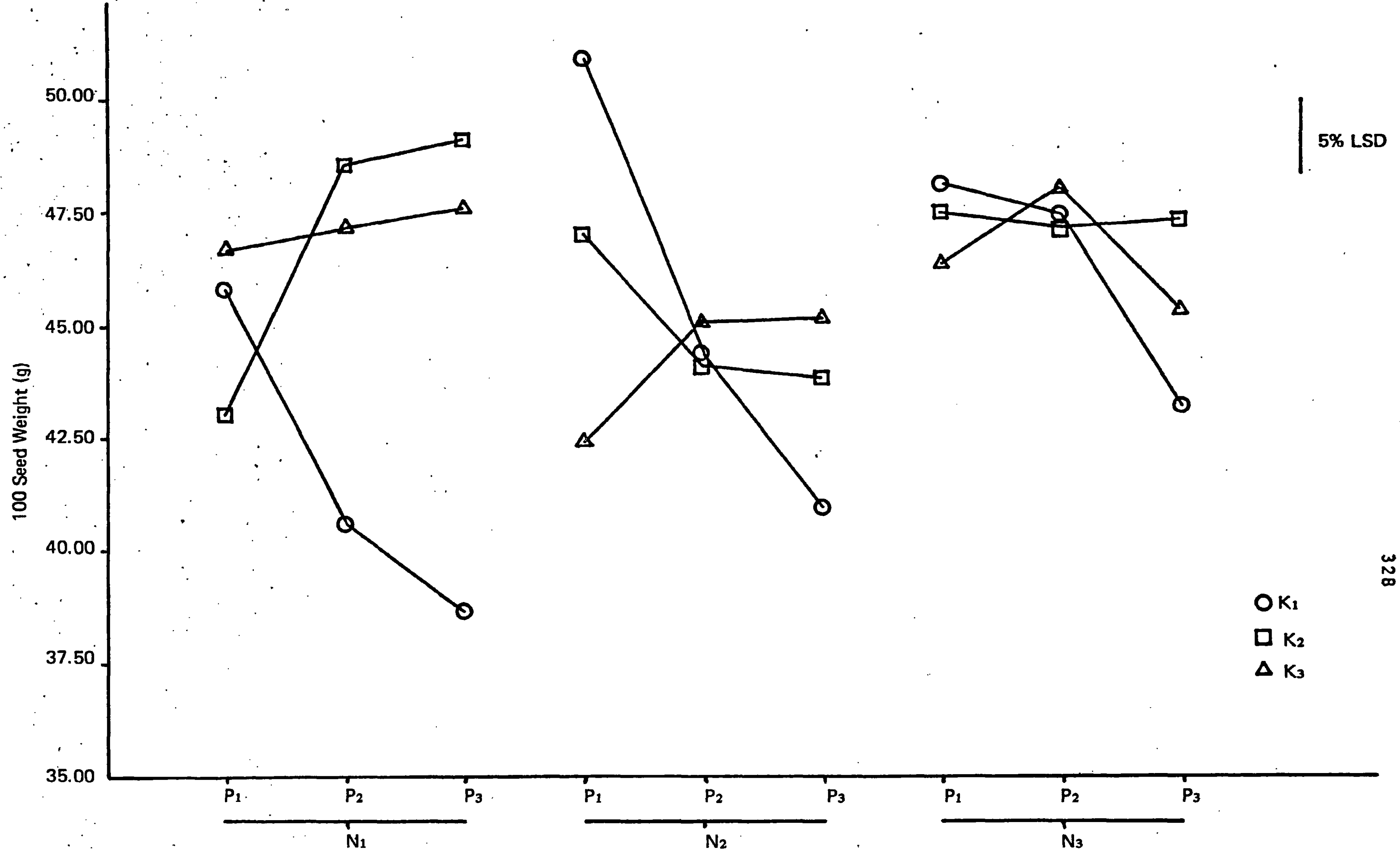

Figure 25 : Effect of NPK Interaction on 100 Seed Weight (Experiment No.2)

In the other two interactions NK and PK, which are present in the 2nd experiment (Tables 82 and 83) the effect of the lowest potassium level is dominant. This level can have good results with higher nitrogen levels and with lower phosphorus levels. The K_2 and K_3 levels gave similar results in all their combinations with nitrogen and phosphorus levels.

The interaction between nitrogen and molybdenum levels which is present in the 3rd experiment (Table 131) confirms the beneficial effect of nitrogen.

The beneficial effect of nitrogen on bean seed size has been reported by Ries (1971), although he did not study the effect of the other main nutrients. A similar nitrogen effect was found by Singh and Cheema (1972) with radish seed, by Lopez and Grube (1973) on wheat seed, by Austin and Longden (1966b) on carrots, and by Soffer and Smith (1974b) with lettuce.

Ivata and Eguchi (1958) working with chinese cabbage found that plants which were supplied with phosphorus during the early stages only, produced a lower seed yield due to smaller size of seeds compared with that of control plants which were supplied with phosphorus during all growth stages. In contrast the results of this study give evidence that bean plants receiving low levels of phosphous produced lower seed yields but larger seeds. Similar results were obtained by Maxon Smith (1976) working with lettuce, who found that liquid feeds without phosphate gave increased seed-weight.

(b) Germination Test

The nitrogen application did not affect the germination percentage (Tables 32, 85, 156) with the exception of the 3rd experiment (Table 132) where the higher nitrogen levels resulted in higher germination percentages than the lowest level; but the differences, although significant, are very small. The seedling dry weight, taken at the 9th day from sowing was significantly affected by nitrogen applications according to the results from the 2nd and 3rd experiments (Tables 89 and 134). The highest level of nitrogen resulted in heavier seedlings. The germination rate was inversely affected in the 2nd and 4th experiments (Tables 87 and 159) e.g. lower nitrogen applications resulted in earlier germination. This is perhaps due to the seed size, since the lower levels of nitrogen produced smaller seeds which can imbibe water during the early stages of germination faster than larger seeds.

Phosphorus significantly affected the germination percentages (Tables 32 and 85), the germination rate and the seedling dry weight (Tables 87 and 89). In all cases the higher levels of phosphorus depressed the germination percentages and the dry weight of the resulting seedlings and reduced the germination rate. The lower the phosphorus available to the mother plant, the higher the germination percentage and the heavier the subsequent seedlings.

As for potassium effects, there is evidence that higher levels of this nutrient to the mother plant can improve germination percentage (Table 156), increase the seedling dry weight (Table 89) and enhance germination (Table 87). These results however, are not consistent as with the other nutrients.

Molybdenum application did not have any effect on the parameters measured during the germination test. From the interactions present in the parameters measured during the germination test, the NP is consistently present in the majority of cases. This interaction between nitrogen and phosphorus levels significantly affected the germination percentage in the 1st, 2nd and 4th experiments (Tables 33, 86 and 157) and the seedling dry weight in the 2nd experiment (Table 90). Looking at the graphs (Figures 27, 28, 29 and 30) it can be seen that the curves follow a similar pattern as the effects of the same interaction on seed size. Thus it seems that the effect of nitrogen depends on phosphorus application. It had a beneficial effect on seed quality when associated with low phosphorus levels. Medium nitrogen levels with higher phosphorus level depressed the germination percentage and reduced the dry weight of the resulting seedlings. The seed quality started to improve again when the highest levels of nitrogen were associated with the highest phosphorus levels.

Another interaction which significantly affected the seedling dry weight in the 2nd experiment (Table 93) is from the levels of the main nutrients N, P and K. The values of seedling dry weight as affected by the NPK interaction are presented in Figure 31. The curves in this figure are similar to those in Figure 25, where the effect of NPK on seed size is presented.

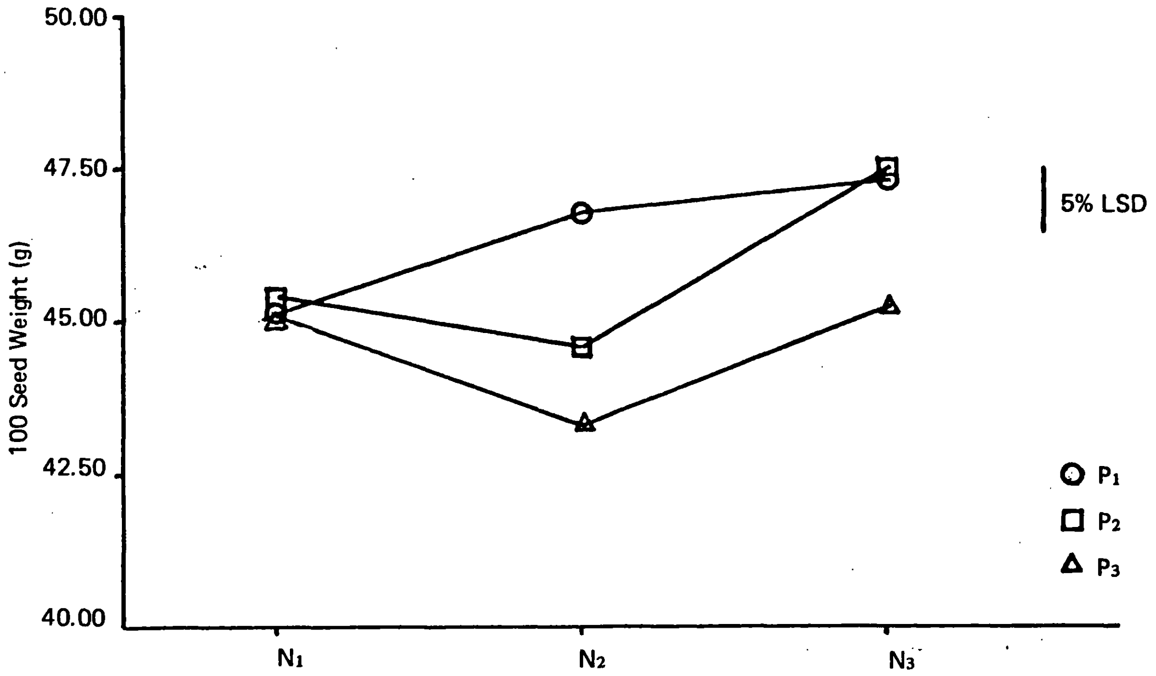

Figure 26 : Effect of NP Interaction on 100 Seed Weight (Experiment No.2)

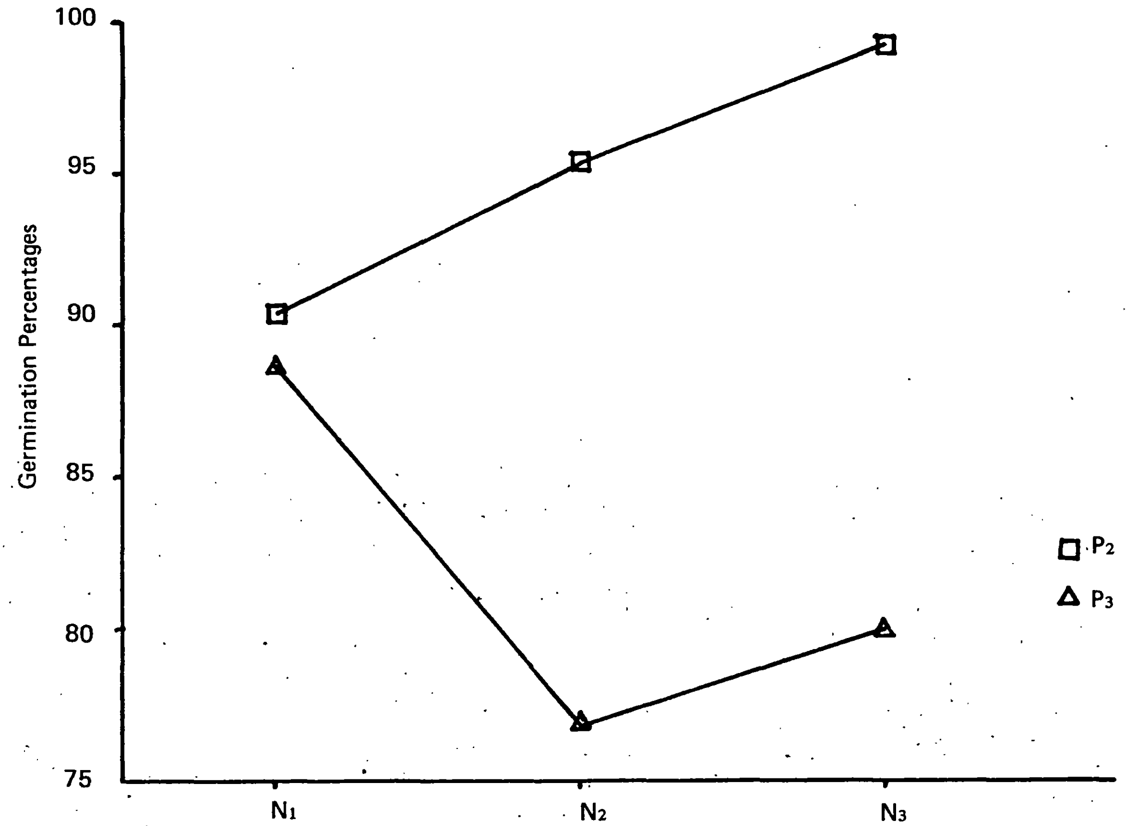

Figure 27 : Effect of NP Interaction on Germination Percentage (Experiment No.1)

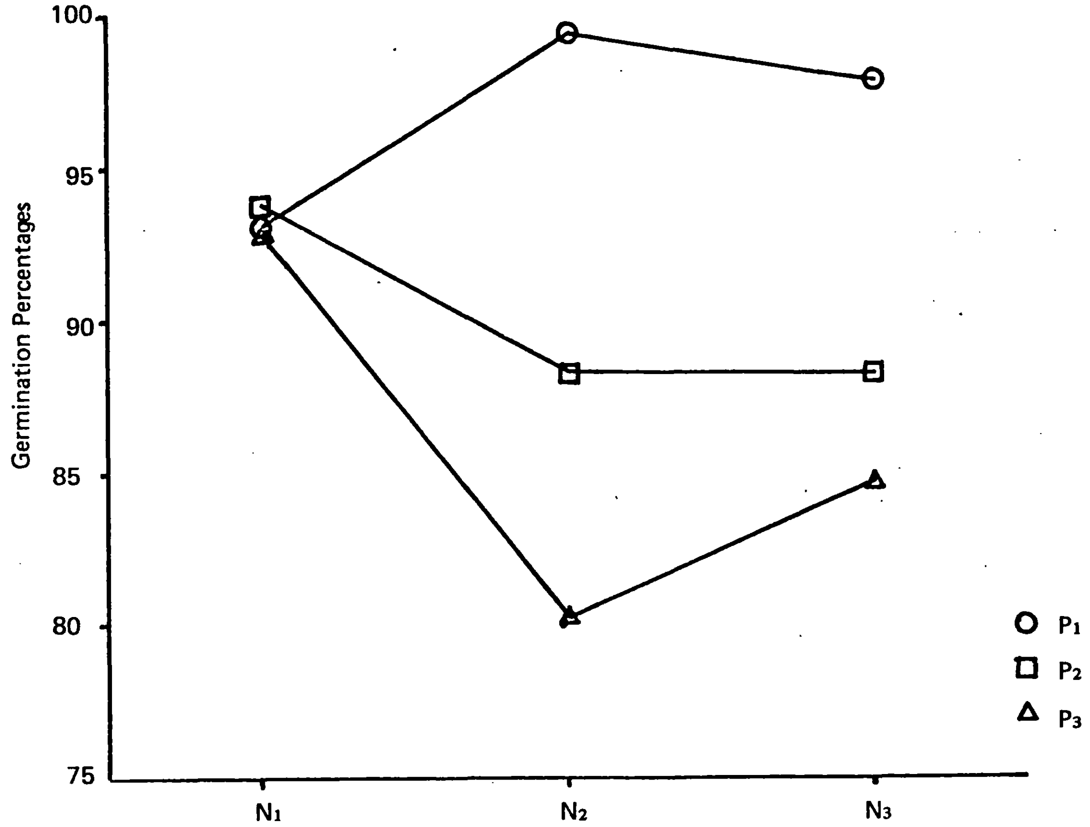

Figure 28 : Effect of NP Interaction on Germination Percentage (Experiment No.2)

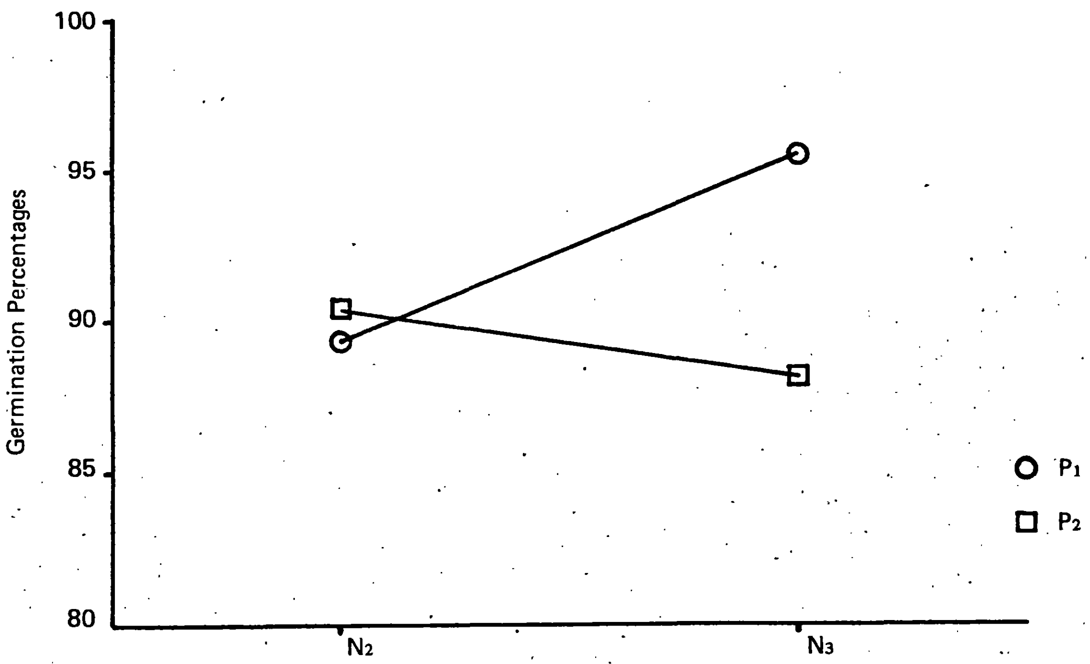

Figure 29 : Effect of NP Interaction on Germination Percentage (Experiment No.4)

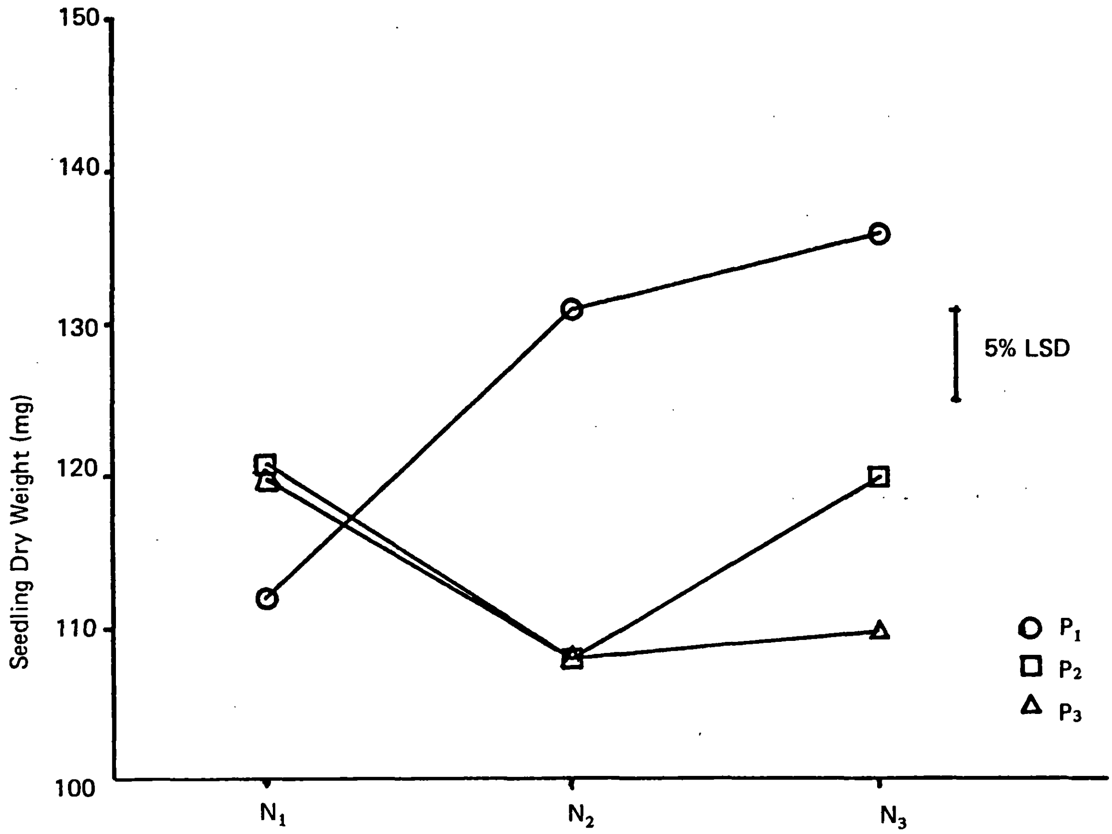

Figure 30 : Effect of NP Interaction on Seedling Dry Weight at the 9th Day From Sowing (Experiment No.2)

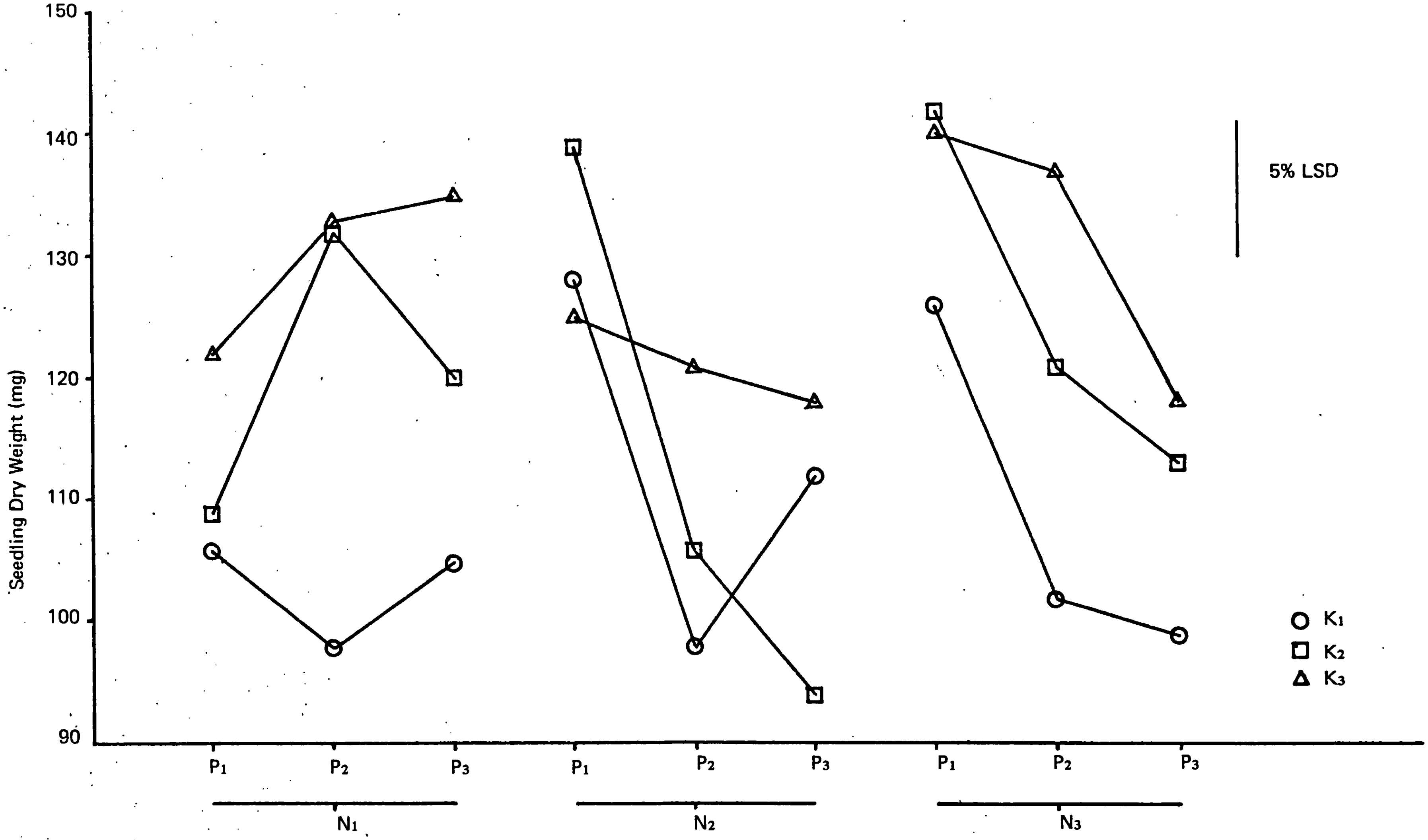

Figure 31 : Effect of NPK Interaction on Seedling Dry Weight At The 9th Day From Sowing (Experiment No.2)

Petkov (1975), from his work on the effect of different nutrients on bean seed quality, found that the combined mineral nutrition with NPK and the micronutrient Mo stimulated the formation of viable seeds with higher germination energy in the laboratory tests and in field tests. He examined the effect of applying two nitrogen levels, two phosphorus levels, their four combinations and only one combination between the three main nutrients NPK. Almost all the other workers examining the effect of mother plant nutrition on seed quality did not find any effect on seed germination. For example, Austin and Longden (1965) did not find differences in germination of watercress, pea and carrot seed due to different mother plant nutrition; Maxon Smith (1976) did not find differences in lettuce germination due to different mother plant phosphorus treatments. Harrington (1960) using low N and P treatments on different species found that K deficiency resulted in lower germination in some of his experiments. The results from Singh and Cheema's (1972) work with radish agrees with the above workers. They did not find significant differences in radish seed germination produced from different mother plant nutrition treatments.

Soffer and Smith (1974b) found a positive linear correlation between N levels and seedling vigour in lettuce seed. Fox and Albrecht (1957) working with wheat found that seedling vigour was influenced by the fertiliser supplied to the mother plant. He observed that during a favourable year seedling emergence was improved when the nitrogen content of the seed had been increased. The effect was not evident or even reversed during the unfavourable year. These workers also found that moderate amounts of phosphorus improved seedling emergence but large quantities depressed it.

(c) Seedling Evaluation Test

This test, carried out in the glasshouse, has been described earlier. During this evaluation the emergence percentage, the emergence rate and the seedling dry weight were measured. The seedlings were harvested when the 1st trifoliate leaf was fully developed (e.g. 3-4 weeks after sowing), and classified as very weak, weak or vigorous.

In none of the four experiments did the nitrogen application to the mother plant have an effect on emergence percentages and on emergence rate (with the exception of the emergence rate in the 3rd experiment). However, a marked effect on seedling dry weight was found due to nitrogen which was highly significant in the 1st and 2nd experiments (Tables 41 and 98), just significant in the 3rd experiment (Table 137) and not significant in the 4th experiment. According to these results the more nitrogen applied to the mother plant the heavier were the seedlings from the seeds produced.

Also in none of the four experiments did the nitrogen application have an effect on the percentages of very weak, weak or vigorous seedlings.

Phosphorus application had a marked effect on emergence percentages (Tables 37 and 94) and on seedling dry weight (Table 98). These results confirm the results obtained in the germination test in which the lower phosphorus levels were found to promote the seed emergence and increase the seedling dry weight, while the higher levels depressed them. Another effect of phosphorus application is on the percentages of weak, very weak and vigorous seedlings. The results (Tables 101, 103 and 104) indicate that the higher mother plant phosphorus levels resulted in weaker and less vigorous seedlings, since the lower levels increased the percentages of vigorous and decreased the percentage of weak seedlings.

Potassium did not have as persistent an effect as the other main nutrients, some of the parameters measured were affected but not in all the experiments. In the 1st experiment the highest potassium level increased the emergence rate (Table 40) and in the 2nd experiment again the highest potassium level resulted in heavier seedlings (Table 98) and in higher percentage of vigorous seedlings (Table 104).

The results from the 1st and 3rd experiments do not provide evidence that there is a molybdenum effect on the parameters measured in the seedling evaluation test.

From the interactions which are present in this test, again the most persistent is between nitrogen and phosphorus levels, which significantly affected the emergence percentage (Tables 38 and 95), the seedling dry weight (Table 99) and the percentage of very weak, and vigorous seedlings (Tables 102 and 105). The results from these effects are presented in Figures 32, 33, 34, 35 and 36 where it can be seen that the curves follow a similar pattern as in previous cases.

Another interaction which significantly affected the seedling dry weight and the percentage of vigorous seedlings is between nitrogen and molybdenum levels in the 3rd experiment (Tables 138, 142 and Figures 37 and 38). From these results it was observed that the very low and very high molybdenum levels in combination with the nitrogen levels depressed the seedling dry weight and the percentages of vigorous seedlings; but medium levels of molybdenum in combination with the higher nitrogen levels promoted heavier and more vigorous seedlings.

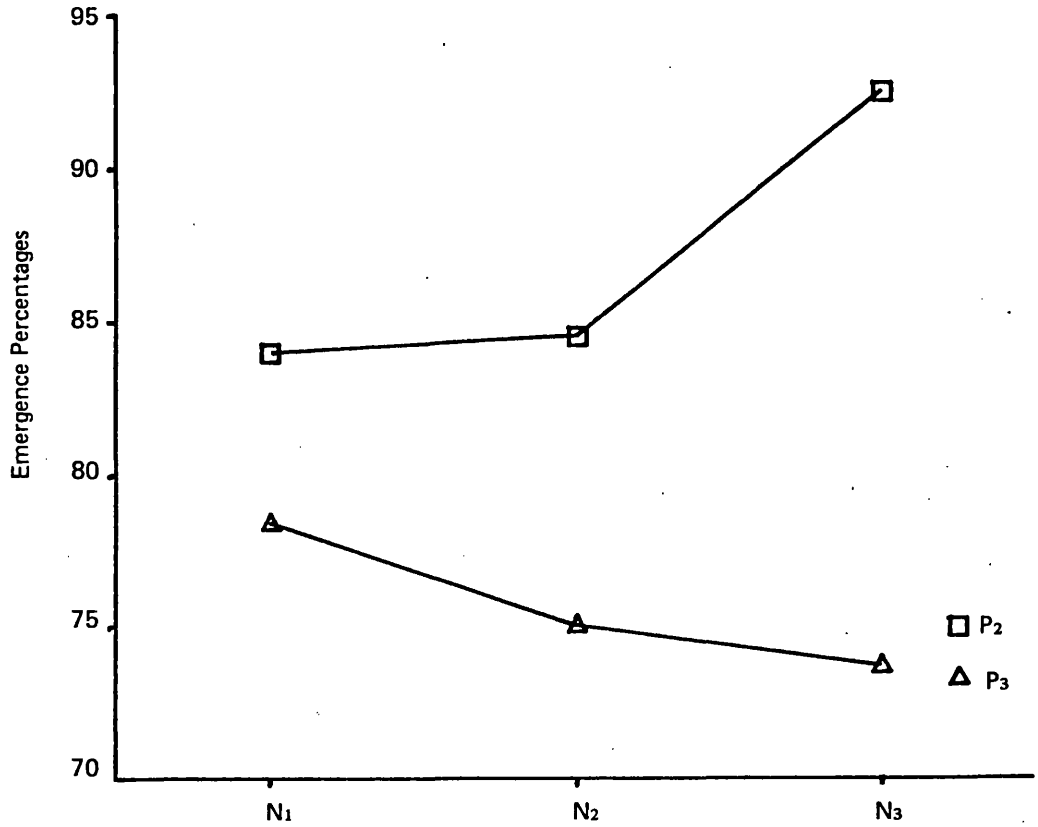

Figure 32 : Effect of NP Interaction on Emergence Percentage (Experiment No.1)

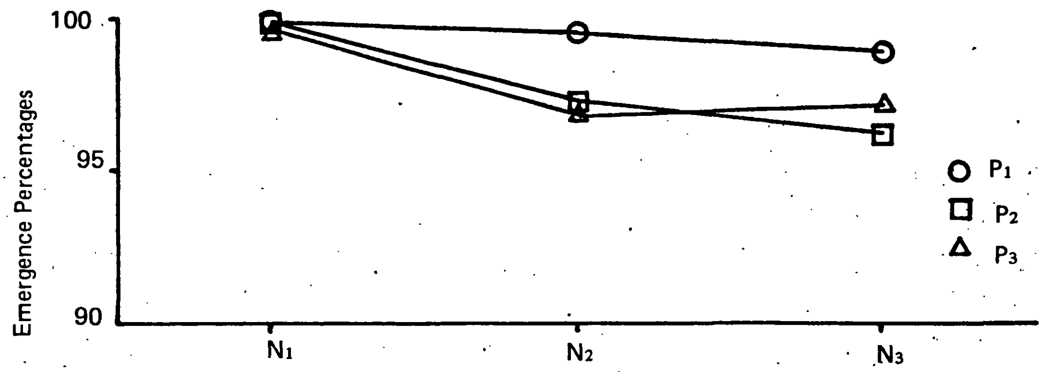

Figure 33 : Effect of NP Interaction on Emergence Percentage (Experiment No.2)

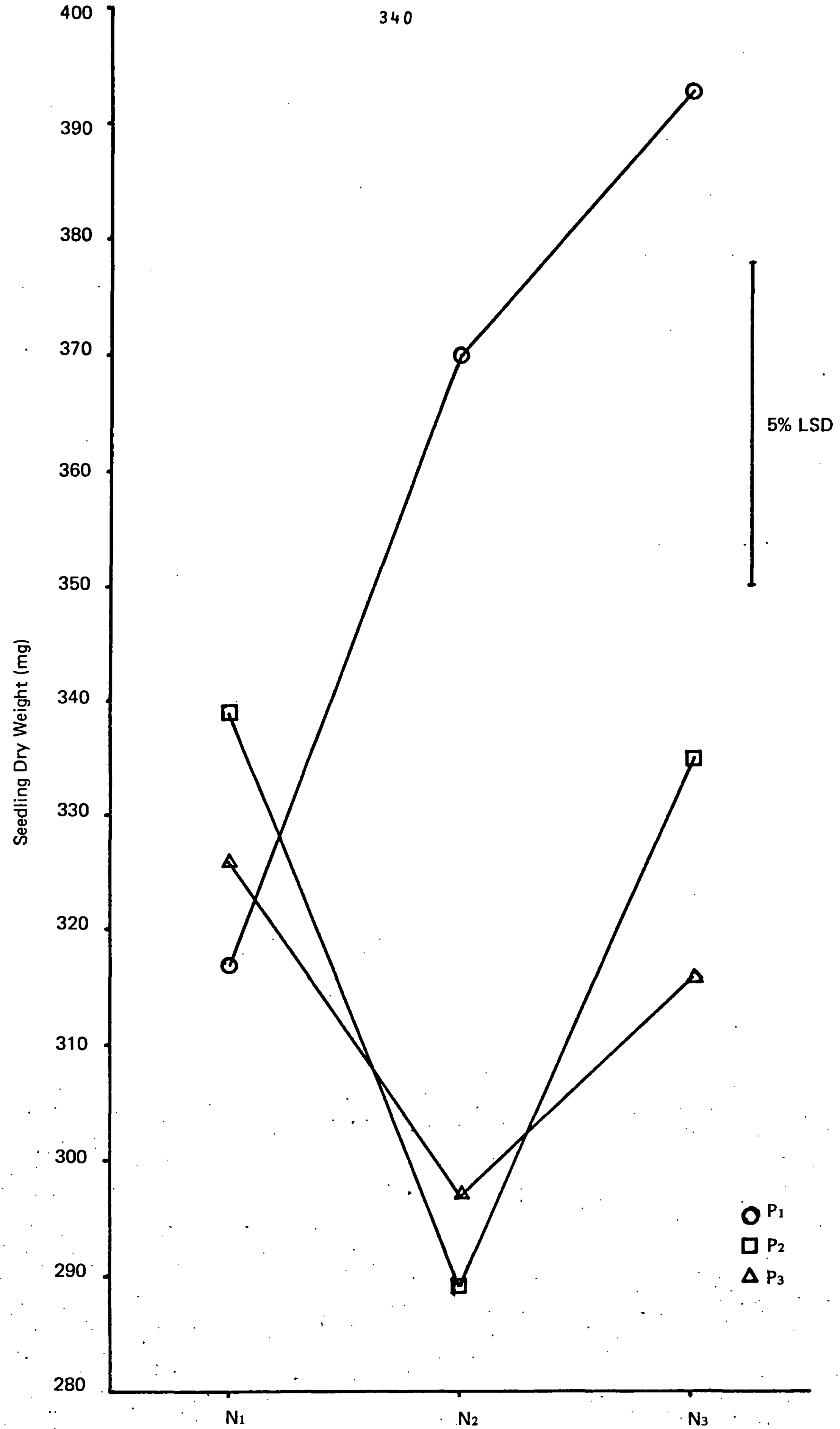

Figure 34 : Effect of NP Interaction on Seedling Dry Weight at 3-4 Weeks After Sowing (Experiment No.2)

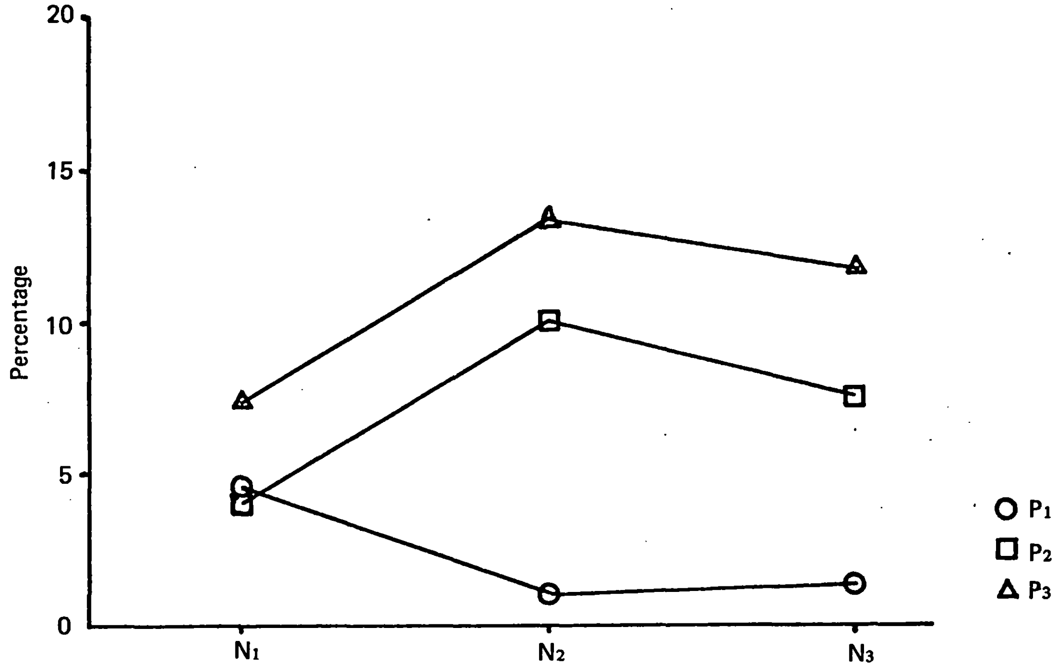

Figure 35 : Effect of NP Interaction on Percentage of Very Weak Seedlings (Experiment No.2)

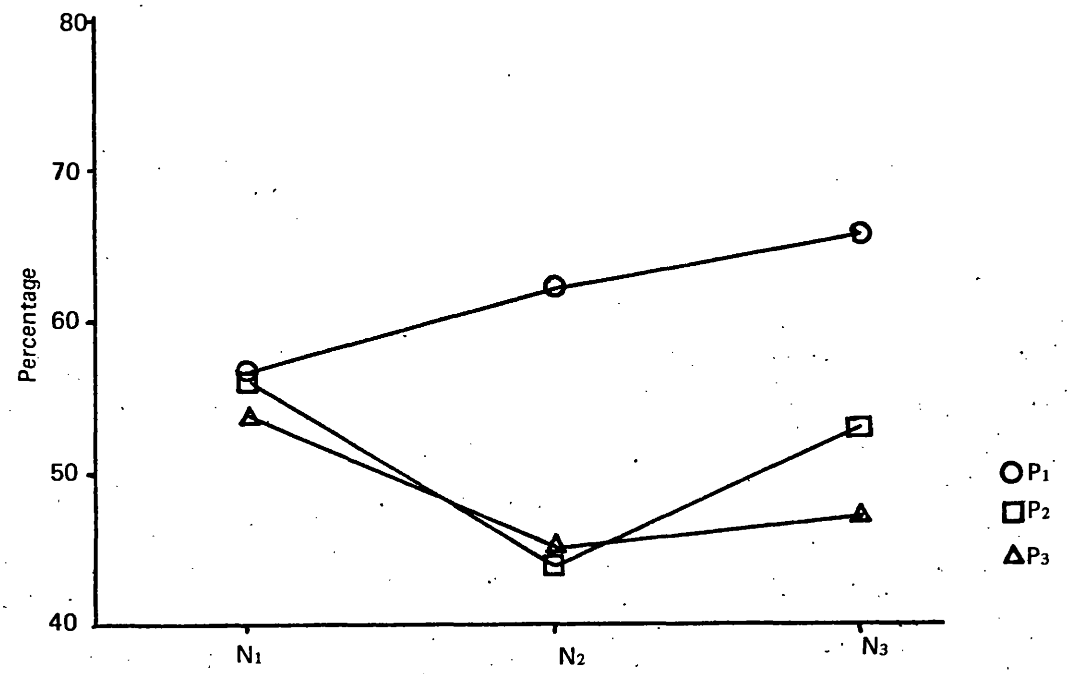

Figure 36 : Effect of NP Interaction on Percentage of Vigorous Seedlings (Experiment No.2)

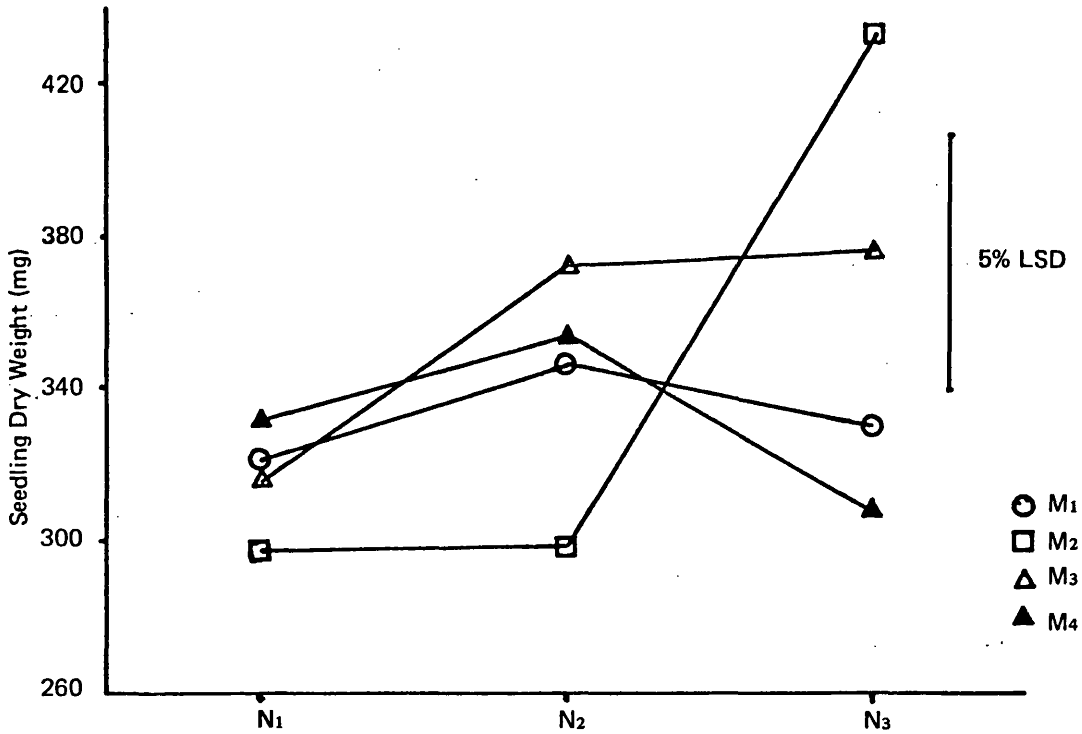

Figure 37 : Effect of NMo Interaction on Seedling Dry Weight at 3-4 Weeks After Sowing (Experiment No.3)

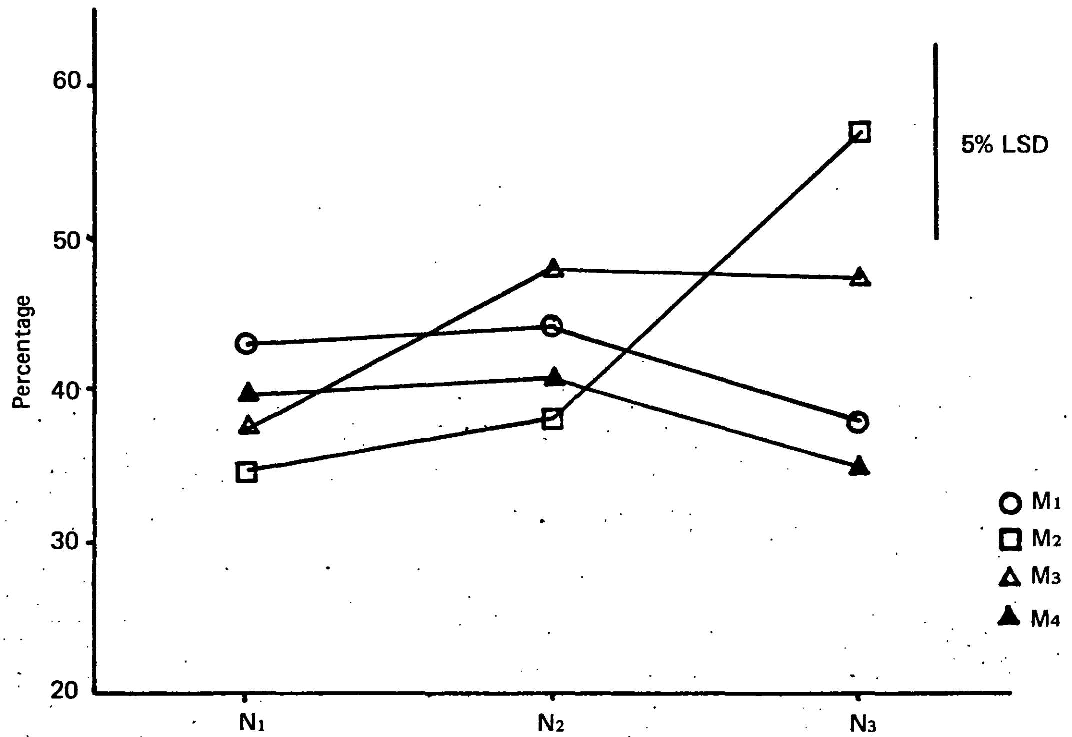

Figure 38 : Effect of NMo Interaction on Percentage of Vigorous Seedlings (Experiment No.3)

(d) Cold Test

According to the results from this test, nitrogen application showed a highly significant effect on seed quality. Seeds produced from plants receiving the highest nitrogen level had the highest germination percentage and the lowest mortality under the unfavourable conditions of the cold test (Tables 106 and 109).

An inverse highly significant effect has been found from phosphorus application. The lowest level of phosphorus results in seeds with the highest emergence and the lowest mortality (Tables 106 and 109).

Potassium just had a significant effect, its highest level resulted in seeds with the highest emergence and lowest mortality (Tables 106 and 109).

As for the molybdenum application, the cold test showed a just significant effect on seed quality. The results (Table 143) provide evidence that the medium levels of molybdenum improved seed emergence under the unfavourable conditions of the cold test.

The interactions of NP and NPK significantly affected the seed emergence in the cold test. The NP interaction (Table 107, Figure 39) is again present as in previous tests. It can be seen that the lowest level of phosphorus in combination with the 2nd and 3rd levels of nitrogen improved the ability of seeds to germinate better under unfavourable conditions. All the other combinations between N and P levels gave very poor emergence.

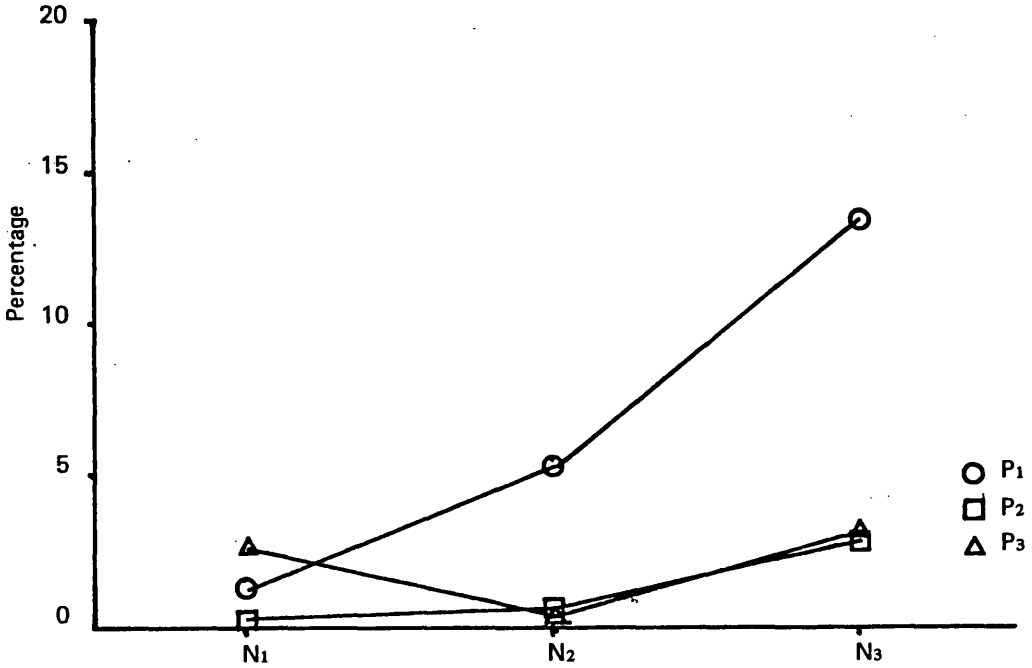

Figure 39 : Effect of NP Interaction on Percentage of Emergence in the Cold Test (Experiment No.2)

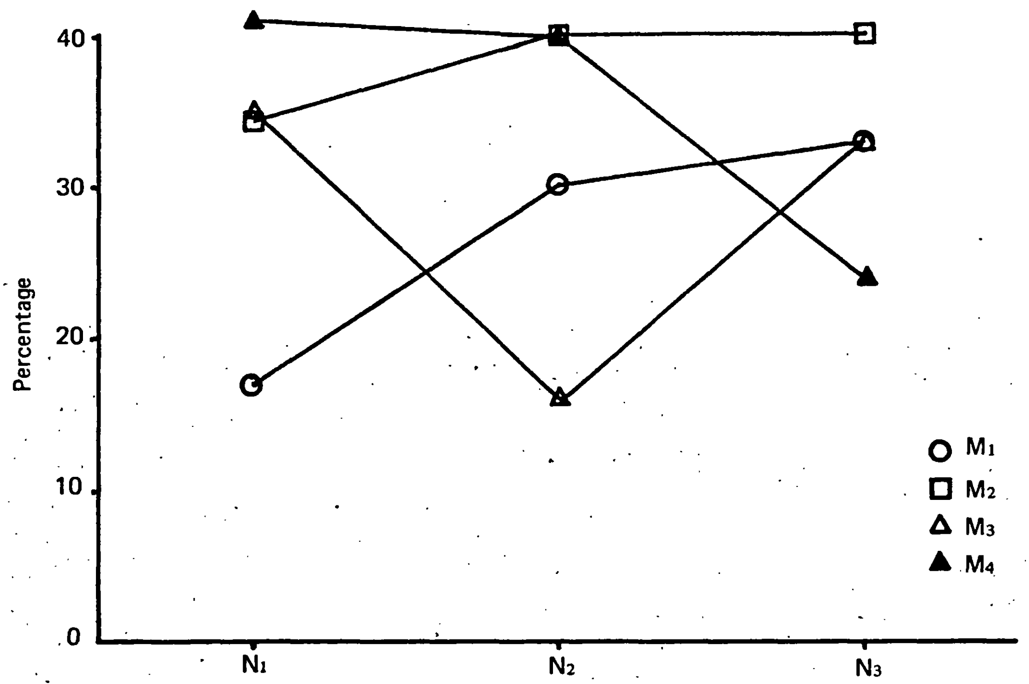

Figure 40 : Effect of NMo Interaction on Percentage of Emergence in the Cold Test (Experiment No.3)

From the results due to NPK interaction (Table 108, Figure 41) it can be seen that not only the NP interaction affected the seed quality but also the K levels in combination with the NP. There is a beneficial effect of the highest level of potassium in combination with the highest nitrogen level and the phosphorus levels, on seed emergence in the cold test. These results are also illustrated in Plate 5 which was taken at the end of the test. The trays containing the seedlings emerged from the different seed lots, rearranged in an order based firstly on phosphorus levels, then on nitrogen levels and finally on potassium levels.

In the 3rd experiment the interaction NMo significantly affected the seed emergence in the cold test (Table 144, Figure 40). It is observed that the lowest molybdenum level has a beneficial effect when it is in combination with the higher levels of nitrogen. In contast, the higher molybdenum levels improve the seed quality when they are combined with the lowest nitrogen level. The medium level of molybdenum gave similar results with all nitrogen levels.

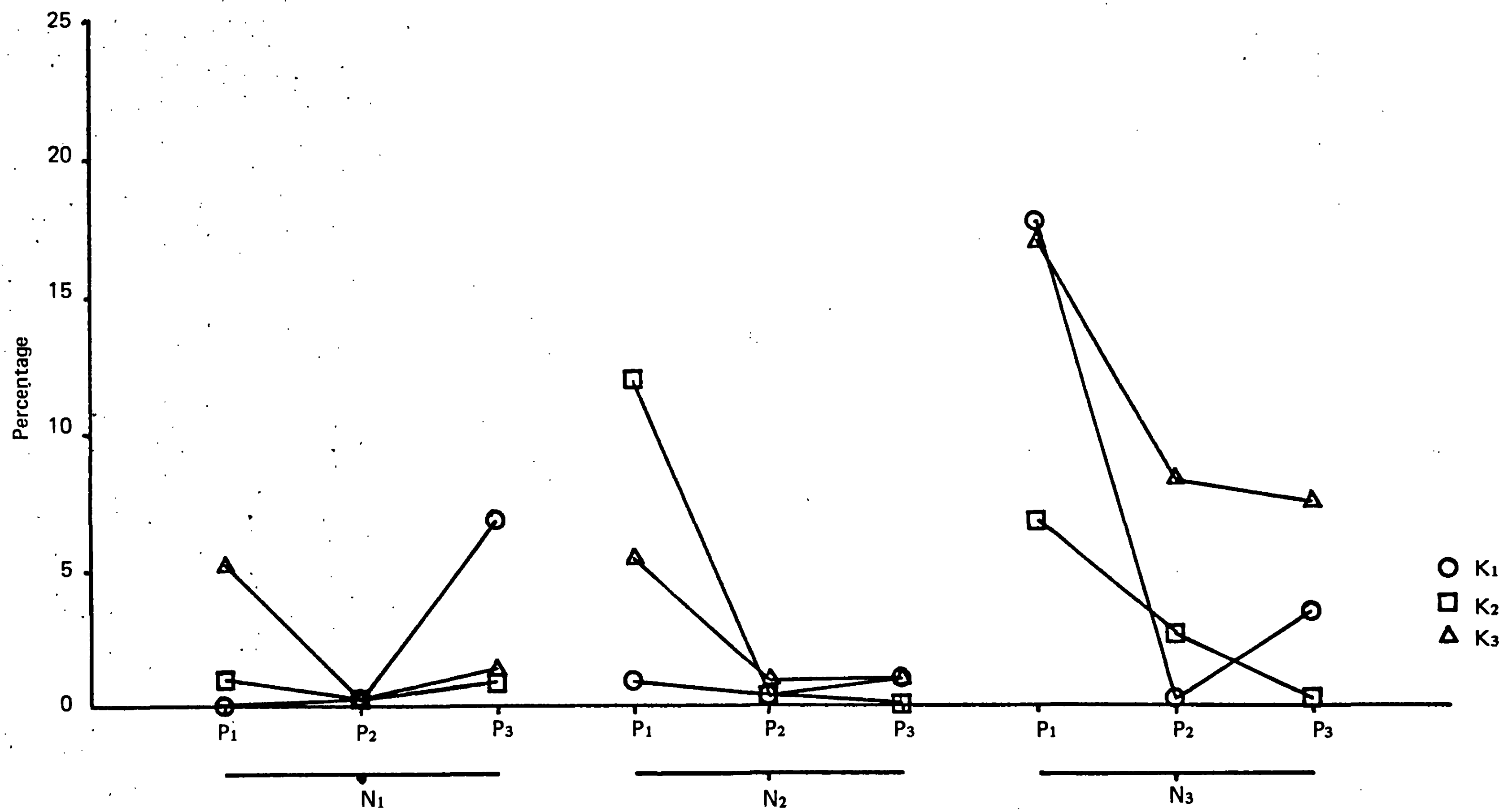

Figure 41 : Effect of NPK Interaction on Percentage of Emergence in the Cold Test (Experiment No.2)

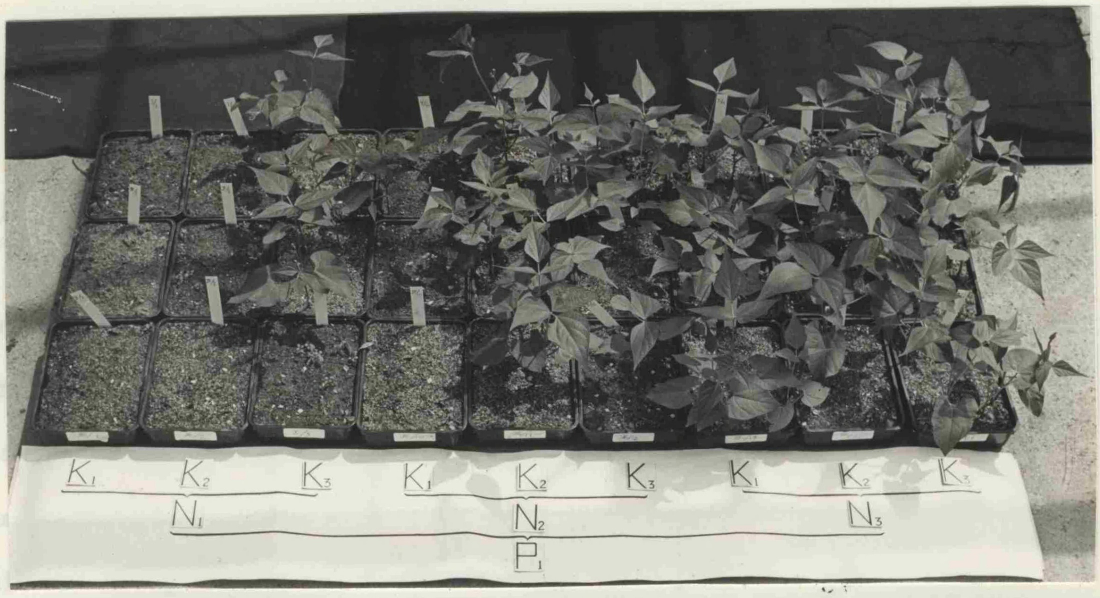

Plate 5 : The Emergence in the Cold Test of the 27 Bean Seed Lots Produced From The 27 Nutritional Treatments in the Mother Plants (Experiment No.2)

(e) *Electrical Conductivity Test*

The results taken from this test for the nitrogen effect are conflicting. In the 2nd experiment (Table 111) the lowest EC reading which corresponds to better seed quality was taken from seeds produced from plants receiving the highest level of N, and this is in agreement with the findings from previous tests. However, in the 3rd experiment seeds from the highest level of N gave a high reading as seed from the lowest N levels (Table 147).

The EC test for phosphorus and potassium effects on seed quality showed similar results as in previous tests (Table 111). Seeds from plants receiving the highest phosphorus level showed a high EC reading and seeds from plants receiving the 2nd and 3rd potassium levels showed a lower EC reading than seeds from the 1st level.

Molybdenum applications did not have an effect on EC readings.

The interactions NP and NPK did not have a significant effect in this test.

The NMo interaction is present but the results taken are not in agreement with those in the cold test.

(f) Seed Chemical Composition

From the results obtained it is concluded that the total seed contents of nitrogen, phosphorus and potassium were affected by the nitrogen, phosphorus and potassium fertiliser levels applied to the mother plants.

High levels of nitrogenous fertilisers increased the seed total nitrogen content and did not affect the seed phosphorus content (Tables 113, 117 and 149). Seed potassium levels decreased with increasing nitrogenous fertiliser levels (Tables 119 and 175) in the 1st and 4th experiments and increased in the 3rd experiment (Table 152).

The increase of seed nitrogen or protein content due to nitrogenous fertiliser has also been found by Ries (1971) with beans; Schweizer and Ries (1969); Lowe, Ayers and Ries (1972) with wheat and oat; Lopez and Grabe (1973) with wheat; Splittstoesser *et al* (1974) with beans; Nicolov (1973) with beans and Stanilova and Velchev (1973) with beans. From Austin and Longden's (1966b) work with carrot seed it was seen that the main variations in seed composition were those resulting from the application of nitrogen, which increased the percentage of seed nitrogen but decreased those of phosphorus and potassium. In contrast, the results from this work show that the phosphorus concentration in the bean seed was unaffected. The same workers, in another trial with radish seed, tried unsucessfully to break this negative correlation between the concentrations of nitrogen and phosphorus by foliar application of urea solutions (Austin and Longden, 1966a).

Phosphorus fertilisers applied in higher levels decreased the seed total nitrogen content (Table 113) and increased the seed phosphorus content (Table 117). The seed potassium content was unaffected. Thus the negative correlation between nitrogen and phosphorus concentrations was found to be due here to phosphorus fertilisers.

Increase in seed phosphorus concentrations due to phosphorus fertilisers has also been found by Hiroce *et al* (1970) with beans; Stanilova and Velchev (1973) with beans; Austin and Longden (1965) with watercress, peas and carrots; and by Szukalski (1961a and b) with rape and flax. Stanilova and Velchev (1973) also found that phosphorus fertilisation at the three rates tested tended to decrease the protein content of the bean seed, this was also found in the present work.

Potassium fertilisers applied to the mother plant did not affect total seed nitrogen content in contrast to Sheveleva's (1973) work with peas and beans, where the seed protein content of peas was reduced in some cases by potassium fertilisers and bean seed protein content increased by 1.1% after an application of 60 Kg K_2O per hectare. But potassium fertilisers decreased the seed phosphorus content (Table 117) and increased the seed potassium content (Table 119).

From the interactions, those which had a significant effect on seed nitrogen content are the NP, NK and NPK (Tables 114, 115 and 116), on seed phosphorus content the NPK (Table 118) and on seed potassium content the NP (Table 120).

Plants receiving the nitrogen levels in combination with the lowest phosphorus level produced seed with a higher nitrogen content. Also, seeds with a high nitrogen content were produced by plants receiving the highest level of nitrogen in combination with the higher levels of phosphorus but not by plants receiving the lower levels of nitrogen in combination with the higher levels of phosphorus. These results of NP interaction are presented in Figure 42, from this it can be seen that the curves follow a similar pattern with those of the NP effect on the previous seed quality tests, with the exception of the P_2 curve.

The NPK interaction effects on seed nitrogen and phosphorus contents are presented in Figures 44 and 45. It can be seen that the seed nitrogen content within each N level is reducing as the phosphorus is increasing. In contrast the seed phosphorus content is increasing with the increase of phosphorus levels. The effect of potassium fertilisers on seed nitrogen and phosphorus content within each N level is not constant and varies according to the nitrogen level.

In the 3rd experiment the interaction between nitrogen and molybdenum levels significantly affected the seed nitrogen content (Table 150, Figure 43). It can be seen that under low nitrogen levels moderate amounts of molybdenum increase the seed nitrogen content.

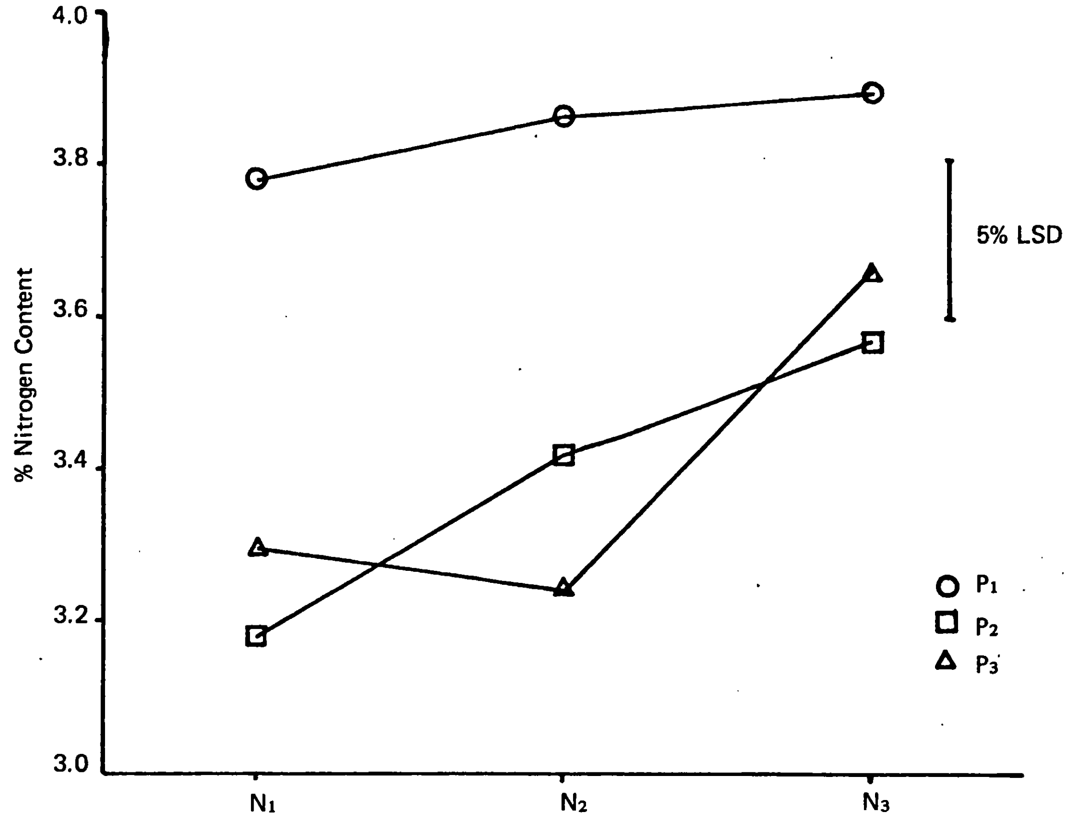

Figure 42 : Effect of NP Interaction on Total Seed Nitrogen Content (Experiment No.2)

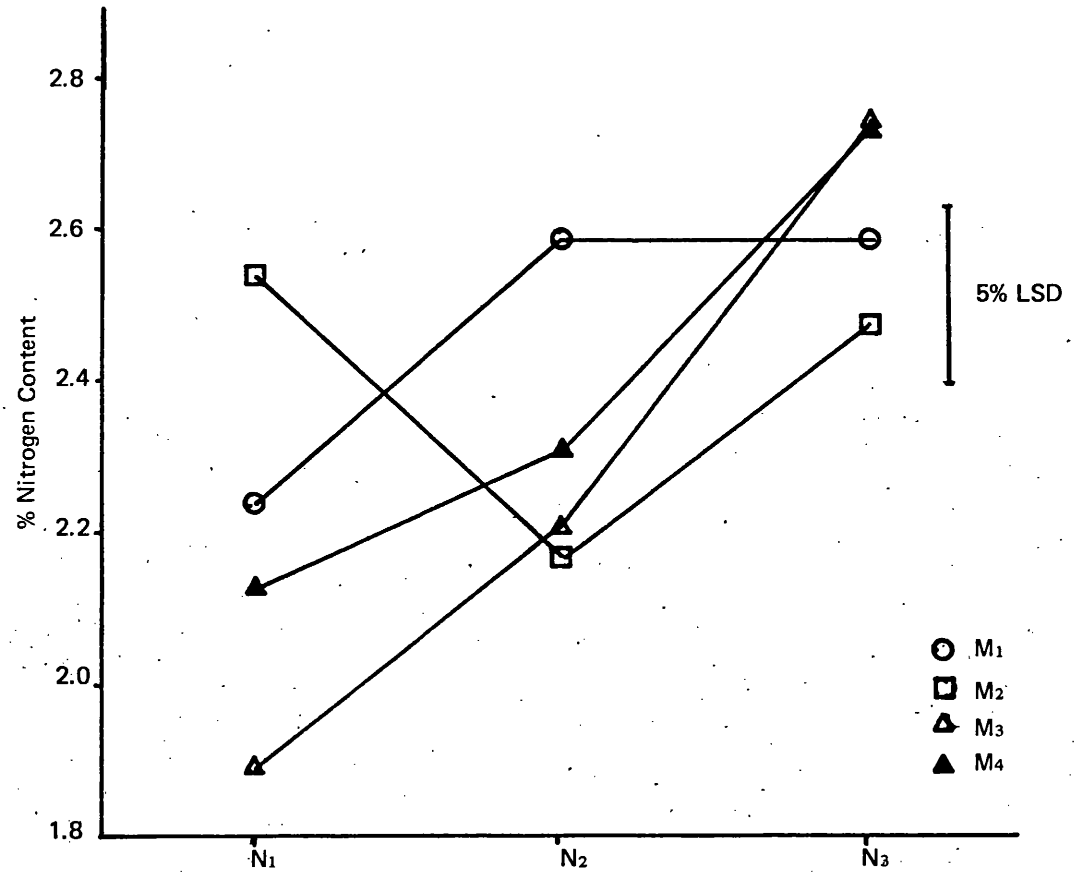

Figure 43 : Effect of NMo Interaction on Total Seed Nitrogen Content (Experiment No.3)

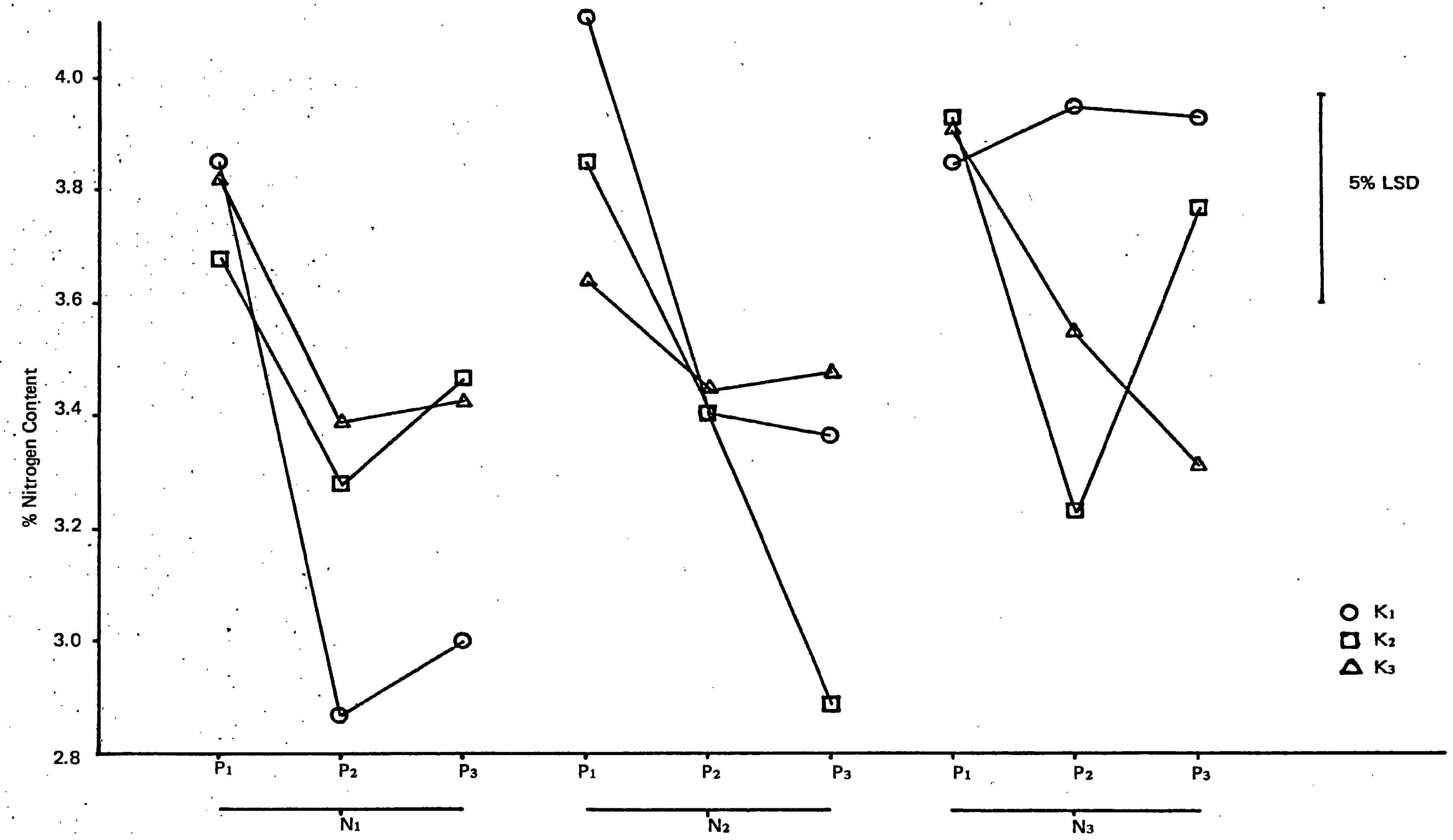

Figure 44 : Effect of NPK Interaction on Total Seed Nitrogen Content (Experiment No.2)

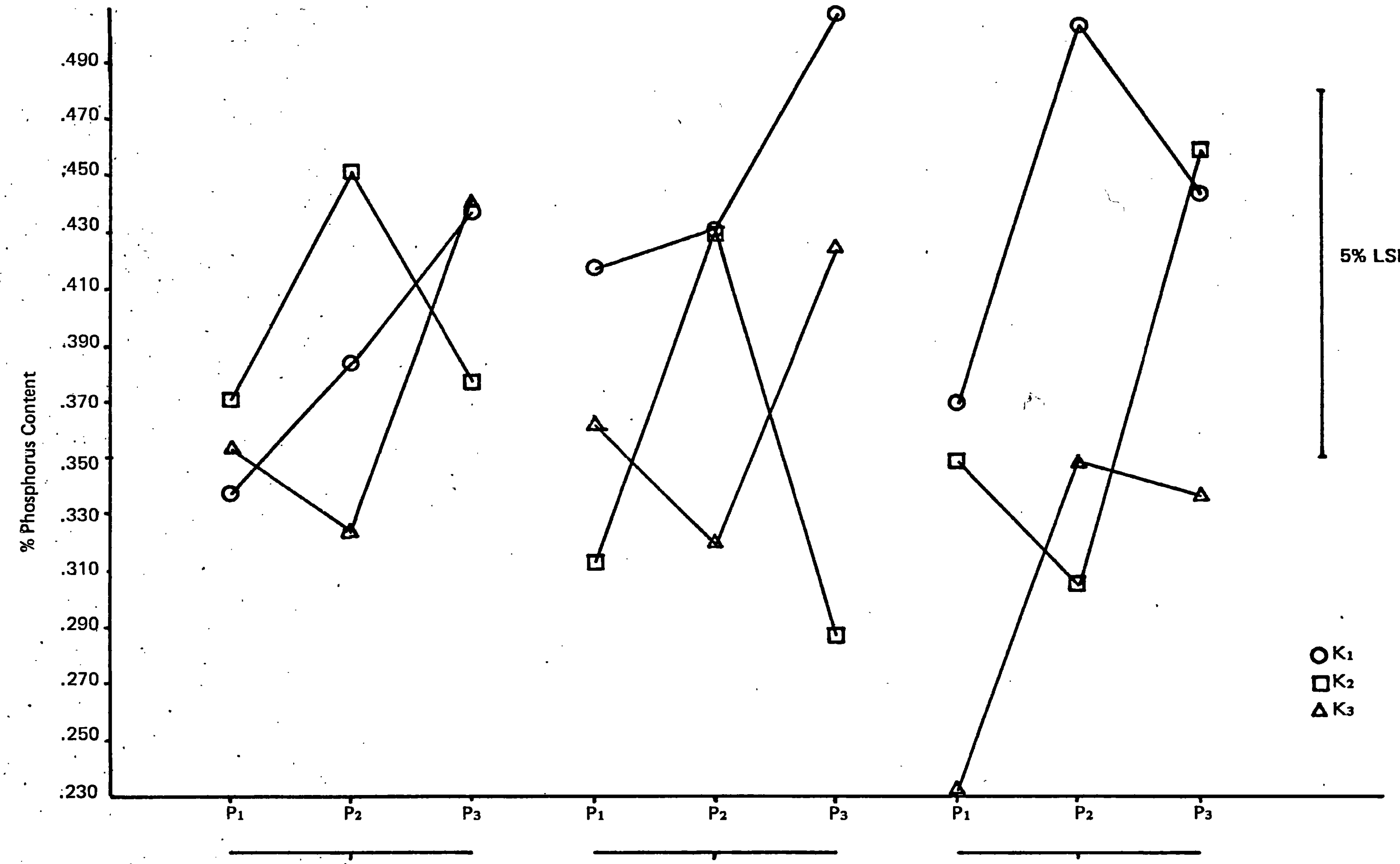

Figure 45 : Effect of NPK Interaction on Seed Phosphorus Content (Experiment No.2)

Conclusions and Suggestions for Further Work

Comparing the different components of seed quality, which have been measured in this work, as affected by the different nutrients applied to the mother plant, the following conclusions are made:

(1) There is strong evidence that nitrogenous fertilisers applied to the mother plant positively affect the quality of seed produced. Increasing these fertilisers applied to the mother plant can produce heavier seed with high germinability under both optimum and adverse conditions. This seed is well supplied with proteins and can produce heavier and vigorous seedlings.

(2) There is evidence that phosphorus fertilisers applied to the mother plant negatively affect the quality of seed produced. Increasing these fertilisers to the mother plant can produce lighter seed with lower germinability under both optimum and adverse conditions. This seed is well supplied with phosphorus but not with proteins, and results in seedlings which are low in vigour and weight.

(3) There is some evidence that potassium fertilisers applied to the mother plant positively affect the quality of seed produced, but the results obtained were not consistent in all the seed quality components. Most of the differences observed were due to the lowest potassium level which was nearer to deficient levels, the other two levels gave better and similar results.

(4) There was no clear evidence of the effects of molybdenum application. Although other workers found a positive relationship between Mo application and seed quality, especially with seed protein content, mostof the results from the work reported here do not give evidence for this relationship. Only some of the results give little evidence that moderate Mo applications improve the seed quality slightly. Perhaps future experiments using water culture, improved monitoring of molybdenum applications and an evaluation of the effects of molybdenum and/or combinations of nitrogen and molybdenum applied to the mother plant will clarify the role of this micronutrient in seed quality. Chemical analysis for protein and molybdenum contents of the seed produced would assist this study.

(5) There is strong evidence that the seed quality is mainly affected by the interactions of the main nutrients. Two of them seem to be very important for the seeds, firstly the NP and secondly the NPK. The NP interaction is present in almost all the components of seed quality and affected them in a similar way. All the combinations of nitrogen levels with the lowest phosphorus level (which was almost at deficient level) produced heavier seeds well supplied with proteins, having better germinability under optimum and adverse conditions. These seeds in turn produced heavier and more vigorous seedlings.

The NPK interaction is not as consistent as the previous one, but it significantly affected several of the components of seed quality in a similar way. The presence of this interaction emphasises the fact that the effect of mother plant nutrition on seed quality is a compound effect of all the main nutrients and micronutrients.

An optimum quantity from each of these nutrients and in a balanced ratio must be given to the mother plant to produce high quality seed. Other workers examining the effect of mother plant nutrition on seed quality did not find this strong evidence for the effect of the different interactions, especially of the NP interaction, mainly because they examined only one nutrient or because they examined specific combinations, but not in a factorial arrangement.
More experiments must be done in containers to examine the NP interacton in greater detail and with more than three levels of each. Similar experiments should also be carried out in the field to determine if the effect of NP interaction is similar to that found above. All these experiments must include seed quality tests and seed chemical analysis for protein and phosphorus contents.
Under the conditions of the experiments in this work it seems that the best results for seed quality were obtained when the main nutrients N, P, K were in a ratio 4:1:1 or 7:1:1.

(6) There is probably a positive relationship between seed quality and seed nitrogen content and a negative one between seed quality and seed phosphorus content, despite Austin and Longden's findings (1965). There also appears to be a negative correlation between seed nitrogen content and seed phosphorus content, due more to phosphorus applications to the mother plant than to nitrogenenous fertilisers, as found by Austin and Longden (1966b) working with carrots. Seed nitrogen and phosphorus levels in the seed seem play an important role in seed quality. Seed nitrogen is closely related to seed proteins, while phosphate is mainly stored in phytin which is the insoluble mixed potassium, magnesium and calcium salt

of myoinositol hexaphosphoric acid (phytic acid). Phytin is invariably present within a globoid in protein bodies (Bewley and Black, 1978). Ries (1971) suggested that vigour and yield of bean seeds are affected by some factor which is closely related to the N content. Perhaps more work on seed nitrogenous and phosphate constituents will help to isolate this factor. Whether or not this can be demonstrated by future work, these factors are closely related to N and/or P content in the seed and the levels found in the seed are related to the nitrogenous and phosphate fertiliser levels received by the mother plant.

(7) The seeds produced from the plants of the 3rd experiment carried out in the Autumn (i.e. in shorter day length), were found to be smaller in size and lower in nitrogen content. This suggests that lower light levels during fruit development in this experiment played a role in affecting the rate of photosynthesis and production of carbohydrates.

Returning to the nutrient levels which resulted in the best plant development and growth and the highest seed yields, and comparing them with those levels which resulted in the highest seed quality, it can be seen that these levels are not the same (Figures 22, 25, 31 and 44) for both seed yield and quality. For example, it was found that the highest yield was obtained with the main nutrients in a ratio 1 : 1.75 : 1.75 (N : P_2O_5 : K_2O) (2nd experiment) and the best seed quality in the same experiment was obtained with the main nutrients in a ratio 4 : 1 : 1 or 7: 1 : 1 (N : P_2O_5 : K_2O).

This is in agreement with Fox and Albrecht's (1957) observation, that the fertilisation of wheat for high yields may not produce seeds which are highest in quality. Wheat seed which came from plants fertilised with large quantities of main nutrients was often among the lowest in giving vigorous seedlings. In contrast Austin and Longden (1966b) in their work with carrots proposed that not only seed yield but also seed quality would benefit from high levels of soil fertility.

Further experiments in the field with beans and other vegetables are needed to clarify this situation. In the proposed experiments, the effects of different fertiliser levels around those recommended for maximum fresh market crop production must be examined. The yield of fresh crop, seed yield and seed quality have to be measured in each of these experments. It is better for these experiments to be carried out in the seed production areas for each vegetable, since a similar trial (Experiment No. 4) of this work with beans in an area not suitable for bean seed production did not provide sufficient information on this aspect of the problem.

2. PROGENY PERFORMANCE

Only one experiment was carried out to examine the progeny performance of bean seed produced from plants receiving different mineral nutrition. Because of practical reasons (space and time), seed lots from only the first experiment were evaluated, and from the 54 seed lots of this experiment only 14 were examined. The 14 seed lots were mainly from mother plants which recieved the lowest and highest levels of the nutrients examined. Seeds from these seed lots were grown under 'Low' and 'High' nutrient regimes as previously described.

The results obtained indicated that there was some effect only during the early stages due to mother plant nutrition, which was not apparent later. The seedling height was measured at the 7th day after seed emergence to access the progeny performance at an early stage. There is strong evidence that this height was affected by the seed lots used (Table 177). It suggests that the effect of mother plant nutrition is reflected in the early progeny performance. The highest seedlings were produced from seeds harvested from mother plants which had received the following nutrient combinations: N_1 P_1 K_1 M_1, N_1 P_1 K_3 M_1, N_3 P_1 K_3 M_2, N_1 P_1 K_2 M_1, N_2 P_1 K_1 M_1, and N_3 P_1 K_1 M_1. It can be seen that the common factor in these combinations is the lowest level of phosphorus (P_1). It suggests that the low phosphorus application to the mother plants resulted in seed which performed better in early stages. These results are in agreement with previous experimental results from this work.

However, these differences in seedling growth due to seed lots produced from plants with different mineral nutrition were not maintained and there was no difference in the final plant growth, measured as stem dry matter, or at their seed yield on both nutrient regimes. The obvious effect of nutrient regime on plant growth and seed yield was found, but within each regime the progeny performed similarly.

In contrast to these results Austin and Longden (1965) working with watercress, peas and carrots found that high phosphorus application to the mother plant resulted in seed with high phosphorus concentration which in turn produced larger plants with slightly higher yields. These differences were obtained when the progeny was grown in solutions deficient in phosphorus. Similar results were found by Szukalski (1961a, b) with rape and flax seed. Also Schweizer and Ries (1969); Lowe, Ayers and Ries (1972) and Ries (1971) showed a positive relationship between protein content of wheat, oat and bean seed on both seedling growth and subsequent yield and with beans the different seed protein levels were induced with nitrogen fertilizers.

From the tests made to examine the quality of the 2nd generation seed there is no indication that there is any residue effect of the 1st generation's mother plant nutrition. The quality of the 2nd generation seed was only affected from it's mother plant nutrition ('High' and 'Low' nutrient regimes). This effect was present on emergence percentage (Table 184) and vigorous seedling percentages (Table 187), were seeds from the 'Low' nutrient regime performed better than seeds from the 'High'. These results confirm results of previous experiments in this work.

Thus, there was no observed evidence of heritable changes of the kind reported by Durrant (1962), this was also concluded by Austin and Longden (1965) from their work with watercress, peas and carrots. However, from the interactions which are present on 100 seed weight (Table 183) and on emergence percentages (Table 186) between nutrient regimes and seed lots there is an indication that the seed lots from the 1st generation produced seed (2nd generation) which performed differently under the two different nutrient regimes. From this observation it can be suggested that the effects of mother plant nutrition can be transferred to subsequent generations but other environmental factors which occur in the mean time mask these effects.

3. HARVEST STAGES AND POD POSITION ON THE MOTHER PLANT

Examining the observations made and the results obtained from the experiments No. 6 and No. 7 it can be seen that the flower position and consequently pod and seed position on the mother plant plays an important role on seed yield and seed quality.

First of all it can be seen that the amount of flowers on secondary branches grown from the axil of trifoliate and primary leaves ('S' position) is slightly bigger than that on the main axis ('M' position) (Table 206). The flowering on the 'S' position took place later than on the 'M' position, with the result that the seed lots, at a given harvest consist of seed of different ages. This difference in flowering was approximately 5 days for the 7th experiment, since from the observations made (Tables 206 and 207) the peaks in flowering sequence occurred on 19th and 24th September respectively. Thus at each harvest stage the seed lot consisted of seed of at least two different ages. However, from Matthew's (1973) work on pea seed it is known that seed age affects seed maturation and quality.

Another difference was observed in the percentages of setting in the flowers of the two positions examined. This percentage fluctuated from 19.93% up to 43.66% in flowers on the 'M' position and from 4.65% up to 15.45% in flowers on the 'S' position (Table 213). Another indication for better setting in the 'M' position produced the effect of the pod position on number of seeds per pod (Tables 190 and 209), pods from the 'M' position had more seeds than from the 'S' position.

An interest conclusion which can be made from the different observations is that, within the 'S' positions the most important one is the secondary branches grown from the axil of primary leaves, since these branches have the biggest percentage of flowers grown in the 'S' positions with better setting and more seeds than in the other 'S' positions. So whenever we speak for the 'S' position in a bean plant, we mean those branches mainly from the axil of primary leaves.

From the seed yield distribution on the main axis and on the secondary branches it can be seen that the amount of seed on the secondary branches is considerable. Under the conditions of the 6th experiment this amount was 40.40% - 51.72% of the total seed yield, and under the conditions of the 7th experiment was 24.40% - 39.87% (Tables 192 and 211). This indicates that the percentage of seed of different age in a seed lot from a given harvest stage is considerable.

The seed yield was almost the same for all the harvests of the 6th experiment and for the last 6 harvests of the 7th experiment. This suggests that the bean seed can be harvested after the 80th day from seed emergence without losses in seed yield. However, the seed moisture content during the early harvests (80-95 days from seed emergence) is very high (50-60%, under the conditions of the experiments made). Seed with a moisture content of 17% and less, in fresh weight, can be obtained after the 95th day from emergence. Comparing these results with those of Silva *et al* (1975b), it can be seen that at the time in which bean seed reaches maximum physiological quality the potential seed yield is at it's maximum level.

The results concerning the seed quality components give evidence that the position of seeds on the mother plant affects the seed quality. The seed size is bigger in seeds from the 'M' position than in seeds from the 'S' position (Tables 196 and 216). The germination characteristics generally were not affected from the seed position, but seeds from the 'S' position had a lower emergence percentage in the 6th experiment (Table 204) and a lower germination percentage in the 7th experiment (Table 220) than seeds from the 'M' position. However, there is a marked effect on the size of the ensuing seedlings at the 9th day after sowing, due to seed position (Tables 200 and 220). Seeds from the 'M' position produced heavier seedlings than seeds from the 'S' position. Also the percentages of vigorous seedlings are higher in seed lots from the 'M' position and the percentages of very weak seedlings are lower in seed lots from the same position (Tables 205 and 225). The cold test did not show any difference in seed lots due to seed position. These findings are similar to those of Matthew's (1973) work with pea seed. He demonstrated that the younger seeds were at their time of harvest the lower was their percentage viability in soil. Although the bean seeds did not show any difference in the cold test resulting from their position, it can be concluded that the younger seeds ('S' position) can be considered lower quality in respect of being of smaller size, lower germination percentage and producing less vigorous seedlings.

The seed quality components were not only affected by the seed position but also by the harvest stages. The results obtained give evidence that bean seed harvested after the 83rd day in the 6th experiment and after the 81st day in the 7th experiment from seed emergence, had a better size (Tables 195 and 215) and the ensuing seedlings were heavier and more vigorous (Tables 199 and 219). These results confirm Silva's *et al* (1975b) results in their work with bean seed. They found that bean seeds have their maximum physiological quality in the period 82 up to 98 days after seed emergence and they recommend the harvests to be at this period. They also found a deterioration in seed quality after this period which was not found in this work, it is suggested that the different seed production environments are responsible for this. However, some seed quality characteristics, such as germination percentage and germination rate, were slightly better in seed harvested very early, before the 80th day from seed emergence (Tables 199, 203 and 219). Similarly the results from the cold test and electro-conductivity test made in seed from the 7th experiment (Table 228) indicate that seed from early harvests is slightly better in quality than seed from later harvests. Perhaps early harvested seed lots which have been left under laboratory conditions to lose excess moisture content, avoided possible environmental conditions of the mother plant which would otherwise have caused a slight deterioration in the late harvested seed.

A similar conclusion was made by Biddle and King (1978) in their work with pea seed. They stated that some deterioration in quality can occur if the peas are left until they reach full maturity (moisture content around 25%).

Apart from the main effects of harvest stage and seed position on seed quality, some interactions between these two factors on seed quality characteristics exist, such as seed size (Tables 198 and 218), seedling dry weight (Tables 202 and 221) and vigorous seedling percentages (Table 227). These interactions indicate that when the seeds are left on the mother plant for a longer time the seeds in the 'S' position improve in their quality and after some time the differences in seed quality in seed from the 'M' and 'S' positions are becoming minimal. Under the conditions of the 6th and 7th experiments this occurred in seed harvested after the 85th day from seed emergence.

Conclusions and Suggestions for Further Work

Following the above discussion these conclusions can be made:

(1) There is evidence that the amount of bean seed on secondary branches, and thus younger in age, is considerable in french beans. However, these observations must be confirmed from experiments in the field and under the conditions of bean seed production areas. It is possible that in the field, and with dense populations, the growth of secondary branches from the axil of primary leaves can be discouraged.

(2) There is an indication that the bean seed position on the mother plant influences the seed quality, especially in early harvesting stages. Seeds from secondary branches are smaller and produce smaller and less vigorous seedlings than seed from the main axis. It remains to be seen from further work if this effect is the same in the field. Further experiments must be carried out in bean seed production area to examine the seed position effect on seed quality in combination not only with different harvest stages but with other factors as well, such as different bean varieties, drying rates, plant populations.

(3) The harvest stage is very important in seed production. Harvests around the 90th day from seed emergence give bigger seed with lower moisture content. The ensuing seedlings from such seeds are bigger and more vigorous. The contradictory results of some germination characteristics and of cold and EC tests indicate

that it is possible that bean seeds harvested at a late stage may be more susceptible to loss of quality. This aspects has to be examined with further experiments, including not only different harvest stages, but also different drying rates and techniques.

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APPENDIX 1 : Daily Air Temperatures in Greenhouse No.6 in 1977. (°C)

Date	APRIL			MAY			JUNE		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	25.0	10.5	17.75	28.0	11.0	19.50	25.0	11.5	18.25
2	27.5	13.0	20.25	25.0	10.5	17.75	24.0	12.0	18.00
3	29.0	12.5	20.75	23.0	11.0	17.00	34.5	12.5	23.50
4	15.0	9.5	12.25	25.0	10.0	17.50	32.5	12.5	22.50
5	25.0	13.0	19.00	27.0	11.0	19.00	25.0	14.0	19.50
6	25.0	14.0	19.50	24.0	11.0	17.50	24.5	12.5	18.50
7	22.5	12.0	17.25	25.0	10.0	17.50	26.0	12.0	19.00
8	27.5	11.0	19.25	26.0	12.0	19.00	29.5	12.5	21.00
9	25.5	8.0	16.75	20.0	10.5	15.25	27.0	12.0	19.50
10	25.0	10.5	17.75	29.0	12.0	20.50	22.0	13.0	17.50
11	26.0	14.0	20.00	23.0	13.0	18.00	21.0	13.0	17.00
12	21.5	14.0	17.75	28.0	11.5	19.75	23.0	12.0	17.50
13	30.0	14.5	22.25	25.0	11.0	18.00	18.5	12.5	15.50
14	28.0	13.5	20.75	28.0	12.0	20.00	16.5	13.5	15.00
15	28.0	12.5	20.25	23.0	12.0	17.50	17.0	14.5	15.75
16	26.0	14.0	20.00	21.0	11.5	16.25	23.0	14.0	18.50
17	27.5	14.0	20.75	21.0	12.0	16.50	19.0	13.0	16.00
18	23.0	11.5	17.25	22.5	12.0	17.25	19.0	14.0	16.50
19	25.0	13.5	19.25	27.0	12.0	19.50	19.5	14.0	16.75
20	20.0	13.5	16.75	22.0	12.0	17.00	22.5	13.0	17.75
21	20.5	14.5	17.50	21.0	13.0	17.00	24.0	12.5	18.25
22	22.0	14.0	18.00	23.5	12.0	17.75	29.0	12.5	20.75
23	27.0	13.5	20.25	23.5	12.5	18.00	29.5	12.5	21.00
24	28.0	10.0	19.00	23.0	12.5	17.75	31.0	13.5	22.25
25	27.0	12.5	19.75	24.0	13.0	18.50	30.5	13.0	21.75
26	22.0	14.5	18.25	28.5	13.0	20.75	30.5	13.5	22.00
27	28.0	10.0	19.00	29.0	12.5	20.75	31.5	13.0	22.25
28	34.0	11.0	22.50	33.0	14.0	23.50	25.5	13.0	19.25
29	26.0	11.0	18.50	31.5	15.0	23.25	28.0	12.5	20.25
30	30.0	11.0	20.50	24.0	12.5	18.25	30.0	14.0	22.00
31	-	-	-	23.5	11.0	17.25	-	-	-

APPENDIX 1 (continued)

Date	JULY			AUGUST			SEPTEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	27.0	14.0	20.50	37.0	14.0	25.50	20.5	16.0	18.25
2	34.0	13.0	23.50	38.5	15.0	26.75	24.0	16.0	20.00
3	37.0	13.0	25.00	34.0	16.0	25.00	33.0	17.0	25.00
4	35.5	16.0	25.75	34.0	14.0	24.00	31.0	15.0	23.00
5	34.0	16.5	25.25	32.0	16.0	24.00	34.00	16.5	25.25
6	34.0	16.0	25.00	22.0	15.0	18.50	26.0	18.0	22.00
7	31.0	15.0	23.00	28.0	15.0	21.50	32.0	16.5	24.25
8	26.0	16.0	21.00	31.0	13.5	22.25	31.5	16.5	24.00
9	26.0	17.0	21.50	36.0	14.0	25.00	32.0	14.5	23.25
10	28.0	17.0	22.50	35.5	14.0	24.75	26.0	15.0	20.50
11	27.5	16.0	21.75	36.0	14.5	25.25	32.0	17.0	24.50
12	25.0	14.5	19.75	34.0	14.0	24.00	29.5	16.0	22.75
13	24.5	13.0	18.75	29.0	15.0	22.00	29.0	12.5	20.75
14	26.0	13.0	19.50	25.5	17.0	21.25	33.0	16.0	24.50
15	30.0	12.0	21.00	32.0	14.5	23.25	26.0	16.0	21.00
16	33.0	14.0	23.50	23.0	16.0	19.50	21.0	17.0	19.00
17	26.0	15.0	20.50	18.0	14.5	16.25	26.0	15.0	20.50
18	31.5	15.0	23.25	26.5	14.0	20.25	24.0	15.0	19.50
19	28.0	14.0	21.00	25.0	14.5	19.75	23.5	16.0	19.75
20	30.0	12.5	21.25	23.0	14.0	18.50	29.0	16.0	22.50
21	26.0	12.5	19.25	32.0	14.5	23.25	24.0	16.0	20.00
22	32.0	15.0	23.50	23.5	15.0	19.25	20.5	16.5	18.50
23	37.0	16.0	26.50	31.5	13.5	22.50	25.0	16.5	20.75
24	32.0	16.0	24.00	20.0	14.0	17.00	21.0	17.0	19.00
25	27.0	14.0	20.50	28.0	13.5	20.75	32.5	16.5	24.50
26	33.0	13.5	23.25	32.0	16.0	24.00	28.0	16.5	22.25
27	31.0	14.0	22.50	25.0	17.0	21.00	24.5	17.5	21.00
28	30.0	14.0	22.00	32.0	15.0	23.50	29.0	17.5	23.25
29	27.0	14.0	20.50	34.0	16.0	25.00	28.5	15.5	22.00
30	36.0	14.0	25.00	27.5	17.5	22.50	24.0	17.0	20.50
31	33.0	15.0	24.00	28.5	16.0	22.25	-	-	-

APPENDIX 1 (continued)

Date	OCTOBER			NOVEMBER			DECEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	29.0	15.0	22.00	20.5	14.0	17.25	21.0	12.5	16.75
2	30.0	16.0	23.00	21.0	11.0	16.00	20.0	13.5	16.75
3	26.0	15.0	20.50	24.0	11.0	17.50	15.0	12.0	13.50
4	27.0	15.5	21.25	24.0	13.0	18.50	10.5	5.0	7.75
5	22.0	13.5	17.75	21.0	13.0	17.00	17.5	6.5	12.00
6	20.5	14.5	17.50	22.0	14.0	18.00	19.0	10.0	14.50
7	26.0	14.5	20.25	22.0	16.5	19.25	20.0	12.5	16.25
8	23.0	14.0	18.50	23.5	16.0	19.75	21.5	12.0	16.75
9	29.0	15.0	22.0	22.5	14.0	18.25	23.0	17.0	20.00
10	29.0	14.5	21.75	27.0	17.0	22.00	26.5	13.5	20.00
11	27.0	15.0	21.00	21.5	14.0	17.75	24.0	15.5	19.75
12	29.0	15.5	22.25	23.5	12.5	18.00	22.5	16.5	19.50
13	28.5	15.0	21.75	25.0	12.5	18.75	20.0	11.5	15.75
14	27.0	15.5	21.25	20.5	12.0	16.25	14.0	14.0	14.00
15	24.5	15.0	19.75	21.0	13.0	17.00	23.0	14.0	18.50
16	26.0	16.0	21.00	25.0	12.0	18.50	17.0	14.0	15.50
17	26.5	15.5	21.00	26.0	12.0	19.00	17.0	15.0	16.00
18	25.0	16.0	20.50	27.0	14.0	20.50	25.0	15.0	20.00
19	21.5	16.5	19.00	21.0	13.0	17.00	19.0	14.5	16.75
20	22.0	16.5	19.25	27.0	16.0	21.50	22.0	15.5	18.75
21	23.0	17.0	20.00	28.0	17.5	22.75	18.0	10.5	14.25
22	27.0	17.0	22.00	25.0	19.0	22.00	21.5	11.5	16.50
23	28.5	17.0	22.75	25.0	20.5	22.75	19.0	15.5	17.25
24	21.0	16.0	18.50	27.5	17.5	22.50	23.0	15.0	19.00
25	28.0	15.0	21.50	27.0	16.5	21.75	18.5	15.0	16.75
26	21.0	15.5	18.25	25.0	17.0	21.00	18.0	15.0	16.75
27	25.5	15.0	20.25	24.5	15.0	19.75	17.0	15.0	16.00
28	26.0	14.5	20.25	23.5	13.0	18.25	20.0	14.0	17.00
29	24.0	16.0	20.00	25.5	11.0	18.25	18.0	14.0	16.00
30	22.5	15.0	18.75	25.0	11.5	18.25	20.0	14.0	17.00
31	22.5	15.0	18.75	-	-	-	19.0	15.0	17.00

APPENDIX 2 : Daily Air Temperatures in Greenhouse No.6 in 1978. (^{o}C)

Date	APRIL			MAY			JUNE		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	32.0	14.0	23.00	20.0	14.5	17.25	39.5	18.5	29.00
2	50.0	9.5	29.75	27.0	14.5	20.75	38.0	18.0	28.00
3	23.0	12.0	17.50	31.0	14.0	22.50	40.0	18.0	29.00
4	21.5	11.0	16.25	32.0	15.0	23.50	38.0	19.0	28.50
5	41.0	9.0	25.00	24.0	15.0	19.50	37.0	18.0	27.50
6	42.5	9.0	25.75	26.0	15.0	20.50	38.0	18.0	28.00
7	28.0	8.0	18.00	29.0	16.0	22.50	27.0	17.0	22.00
8	22.0	12.5	17.25	25.0	16.0	20.50	33.0	18.0	25.50
9	22.5	14.0	18.25	31.5	15.5	23.50	38.0	18.0	28.00
10	29.0	13.5	21.25	38.5	15.0	26.75	37.0	17.0	27.00
11	29.0	12.5	20.75	29.0	16.0	22.50	41.0	17.0	29.00
12	29.5	13.0	21.25	37.0	15.5	26.25	31.0	18.0	24.50
13	27.0	13.5	20.25	39.0	15.0	27.00	28.0	16.0	22.00
14	28.0	12.0	20.00	38.5	15.0	26.75	28.0	15.0	21.50
15	29.0	14.0	21.50	37.0	14.5	25.75	27.0	17.0	22.00
16	29.5	15.0	22.25	34.0	14.5	24.25	34.0	17.0	25.50
17	29.0	14.0	21.50	38.5	14.5	26.50	28.0	17.0	22.50
18	21.0	12.5	16.75	34.0	13.5	23.75	36.0	15.0	25.50
19	24.0	15.0	19.50	40.0	14.0	27.00	43.5	17.5	30.50
20	28.0	14.0	21.00	38.0	14.0	26.00	40.0	18.0	29.00
21	21.0	14.0	17.50	39.0	14.0	26.50	35.5	13.0	24.25
22	28.0	16.0	22.00	46.0	16.0	31.00	39.5	17.0	28.25
23	31.0	16.0	23.50	45.5	15.0	30.25	37.0	16.5	26.75
24	29.0	13.0	21.00	29.0	16.0	22.50	36.0	17.0	26.50
25	21.0	14.0	17.50	36.0	16.0	26.00	38.5	17.0	27.75
26	19.0	12.5	15.75	33.0	15.5	24.25	31.0	17.5	24.25
27	28.0	13.0	20.50	35.0	16.0	25.50	31.5	14.5	23.00
28	25.0	13.5	19.25	34.5	17.0	25.75	35.5	15.5	25.50
29	28.0	14.0	21.00	35.0	16.5	25.75	34.0	16.0	25.00
30	27.0	12.0	19.50	36.5	16.5	26.50	34.0	15.5	24.75
31	-	-	-	37.0	17.5	27.25	-	-	-

APPENDIX 2 (continued)

Date	JULY			AUGUST			SEPTEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	24.5	15.5	20.00	31.0	17.5	24.25	29.0	18.0	23.50
2	36.0	15.0	25.50	36.5	17.0	26.75	33.0	16.0	24.50
3	37.0	14.0	25.50	36.0	18.0	27.00	34.0	14.0	24.00
4	30.5	15.5	23.00	34.0	18.0	26.00	45.0	14.0	29.50
5	37.0	17.5	27.25	32.0	15.0	23.50	26.0	16.0	21.00
6	26.0	18.0	22.00	32.5	18.0	25.25	33.5	17.0	25.25
7	30.5	18.0	24.25	36.0	18.0	27.00	42.0	17.0	29.50
8	34.0	18.0	26.00	32.0	18.0	25.00	33.0	18.0	25.50
9	32.5	15.0	23.75	30.0	18.0	24.00	27.0	17.0	22.00
10	28.0	18.0	23.00	34.0	17.5	25.75	30.0	18.0	24.00
11	28.5	17.5	23.00	32.0	18.0	25.00	28.0	18.0	23.00
12	39.5	17.0	28.25	32.0	18.0	25.00	34.0	13.0	23.50
13	42.0	18.0	30.00	34.5	18.0	26.25	29.0	15.0	22.00
14	36.0	17.0	26.50	32.0	18.5	25.25	32.5	13.0	22.75
15	38.0	17.0	27.50	34.5	18.0	26.25	31.0	14.0	22.50
16	38.0	13.0	25.50	32.5	17.5	25.00	35.0	19.0	27.00
17	37.5	18.0	27.75	35.0	17.5	26.25	32.5	18.0	25.25
18	35.5	18.0	26.75	31.0	18.0	24.50	31.5	10.5	21.00
19	34.0	18.0	26.00	36.0	18.0	27.00	31.0	15.5	23.25
20	36.0	18.0	27.00	37.0	18.5	27.75	35.0	15.0	25.00
21	37.0	18.0	27.50	35.5	18.0	26.75	35.0	16.0	25.50
22	33.0	18.0	25.50	34.0	19.0	26.50	27.5	15.0	21.25
23	26.0	18.0	22.00	30.5	18.0	24.25	34.5	14.5	24.50
24	37.5	17.5	27.50	34.0	17.5	25.75	32.0	16.0	24.00
25	34.0	17.5	25.75	30.5	17.0	23.75	32.0	15.5	23.75
26	36.0	18.0	27.00	31.0	15.5	23.25	35.0	14.5	24.75
27	35.0	18.0	26.50	33.0	16.0	24.50	32.5	14.5	23.50
28	41.0	18.5	29.75	35.5	18.0	26.75	25.0	15.0	20.00
29	38.5	18.0	28.25	30.5	17.0	23.75	26.0	14.0	20.00
30	28.0	18.0	23.00	30.5	18.0	24.25	25.0	14.0	19.50
31	24.0	18.0	21.00	24.0	13.0	18.50	-	-	-

APPENDIX 2 (continued)

Date	OCTOBER			NOVEMBER			DECEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	31.5	14.0	22.75	27.5	17.5	22.50	19.5	7.5	13.50
2	31.5	13.0	22.25	27.5	17.5	22.50	22.0	9.0	15.50
3	31.5	15.0	23.25	27.0	15.5	21.25	22.0	14.0	18.00
4	32.5	13.0	22.75	24.0	18.0	21.00	33.0	14.5	23.75
5	31.0	14.5	22.75	26.0	18.0	22.00	21.0	11.5	16.25
6	32.0	15.0	23.50	24.5	15.5	20.00	20.5	11.0	15.75
7	30.0	15.0	22.50	26.0	13.5	19.75	23.5	10.0	16.75
8	30.0	15.0	22.50	29.0	17.5	23.25	25.0	14.0	19.50
9	27.0	16.0	21.50	27.0	15.5	21.25	30.0	16.0	23.00
10	27.5	15.5	21.50	28.0	17.0	22.50	24.5	16.0	20.25
11	31.0	16.0	23.50	25.0	15.0	20.00	24.0	16.0	20.00
12	33.0	15.5	24.25	26.0	15.0	20.50	25.0	13.5	19.25
13	27.0	15.0	21.00	26.0	13.5	19.75	24.0	11.5	17.75
14	27.5	15.0	21.25	26.0	15.0	20.50	23.0	12.5	17.75
15	28.5	16.0	22.25	26.0	17.5	21.75	24.0	14.0	19.00
16	25.5	14.0	19.75	25.0	18.5	21.75	22.0	12.0	17.00
17	25.0	14.0	19.50	25.0	15.0	20.00	24.0	12.0	18.00
18	27.0	12.5	19.75	24.0	16.0	20.00	23.0	10.0	16.50
19	23.5	15.0	19.25	22.0	16.0	19.00	25.5	3.0	14.25
20	30.5	16.0	23.25	25.0	13.0	19.00	26.0	3.5	14.75
21	25.5	16.0	20.75	24.0	15.0	19.50	26.0	9.5	17.75
22	30.0	16.5	23.25	28.0	15.0	21.50	25.0	14.5	19.75
23	31.0	14.5	22.75	29.0	14.0	21.50	30.0	15.0	22.50
24	27.0	17.0	22.00	28.0	15.0	21.50	25.0	14.0	19.50
25	31.0	17.0	24.00	23.5	10.0	16.75	31.5	16.0	23.75
26	27.0	17.5	22.25	22.5	11.0	16.75	27.0	17.0	22.00
27	29.0	17.0	23.00	26.5	11.0	18.75	27.0	17.0	22.00
28	25.5	17.0	21.25	24.0	9.0	16.50	31.0	18.0	24.50
29	22.0	15.5	18.75	26.0	11.0	18.50	33.0	18.0	25.50
30	22.5	16.0	19.25	20.0	12.5	16.25	26.0	14.0	20.00
31	26.5	17.0	21.75	-	-	-	16.0	12.0	14.00

APPENDIX 3 : Daily Air Temperatures in Greenhouse No.8 in 1978. (^{o}C)

Date	APRIL			MAY			JUNE		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	23.0	16.0	19.50	22.0	22.0	22.00	32.0	24.0	28.00
2	29.0	14.0	21.50	24.0	21.5	22.75	32.0	16.5	24.25
3	25.0	14.5	19.75	29.0	20.5	24.75	33.0	16.0	24.50
4	25.0	19.5	22.25	30.0	22.0	26.00	29.0	17.0	23.00
5	28.0	13.0	20.50	24.5	22.0	23.25	27.0	17.0	22.00
6	27.0	13.0	20.00	24.5	22.0	23.25	27.0	17.0	22.00
7	26.0	16.0	21.00	26.0	23.0	24.50	22.0	16.0	19.00
8	23.5	19.5	21.50	24.0	23.0	23.50	26.0	16.0	21.00
9	23.5	22.5	23.00	27.0	23.0	25.00	26.0	16.0	21.00
10	28.0	21.5	24.75	29.0	23.0	26.00	29.0	15.0	22.00
11	32.0	18.5	25.25	27.0	22.0	24.50	30.0	14.0	22.00
12	32.0	21.5	26.75	27.0	23.0	25.00	26.0	16.0	21.00
13	26.5	22.0	24.25	28.0	22.0	25.00	23.0	15.0	19.00
14	24.0	20.5	22.25	27.5	22.0	24.75	24.0	15.0	19.50
15	30.0	20.0	25.00	27.0	22.0	24.50	21.0	15.0	18.00
16	26.5	22.0	24.25	27.0	22.0	24.50	28.0	15.0	21.50
17	27.5	21.5	24.50	27.0	21.0	24.00	27.0	15.0	21.00
18	24.0	22.5	23.25	26.0	22.0	24.00	30.0	14.0	22.00
19	24.0	22.0	23.00	29.0	21.5	25.25	32.5	15.5	24.00
20	26.0	22.5	24.25	30.0	22.0	26.00	29.0	17.0	23.00
21	24.0	22.0	23.00	28.5	22.0	25.25	28.0	16.0	22.00
22	26.0	22.0	24.00	30.0	22.0	26.00	27.5	16.0	21.75
23	27.0	22.0	24.50	28.0	22.0	25.00	28.0	16.0	22.00
24	28.0	22.0	25.00	25.0	22.0	23.50	26.5	15.0	20.75
25	22.0	22.0	22.00	27.0	22.0	24.50	28.0	15.0	21.50
26	22.0	22.0	22.00	30.0	22.0	26.00	24.5	16.0	20.25
27	24.5	21.0	22.75	31.0	22.0	26.50	27.5	13.0	20.25
28	24.0	19.0	21.50	32.0	22.0	27.00	28.0	18.0	23.00
29	27.0	22.0	24.50	31.0	22.0	26.50	26.5	22.0	24.25
30	24.0	22.0	23.00	32.5	17.0	24.75	28.0	22.0	25.00
31	-	-	-	32.5	17.5	25.00	-	-	-

APPENDIX 3 (continued)

Date	JULY			AUGUST			SEPTEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	24.0	21.5	22.75	26.0	18.0	22.00	31.0	18.5	24.75
2	30.0	22.0	26.00	33.0	18.0	25.50	32.0	17.0	24.50
3	31.0	23.0	27.00	37.5	17.0	27.25	31.5	16.5	24.00
4	30.0	22.5	26.25	31.0	15.0	23.00	37.5	16.0	26.75
5	28.0	22.0	25.00	24.0	17.0	20.50	20.5	18.0	19.25
6	33.0	24.0	28.50	28.0	15.0	21.50	30.5	17.0	23.75
7	24.0	24.0	24.00	33.0	16.0	24.50	35.0	18.5	26.75
8	27.5	25.0	26.25	30.0	17.0	23.50	29.0	20.5	24.75
9	29.0	24.0	26.50	25.0	17.0	21.00	27.0	20.0	23.50
10	28.0	24.0	26.00	31.0	16.0	23.50	26.5	20.0	23.25
11	26.5	24.0	25.25	28.0	17.0	22.50	28.0	19.5	23.75
12	32.5	24.0	28.25	29.0	16.0	22.50	32.0	16.5	24.25
13	35.0	25.0	30.00	27.5	16.0	21.75	25.5	17.0	21.25
14	34.0	24.0	29.00	29.0	17.0	23.00	31.0	13.5	22.25
15	32.5	22.0	27.25	28.0	17.5	22.75	29.0	16.0	22.50
16	32.0	24.0	28.00	30.5	16.0	23.25	34.0	18.5	26.25
17	28.0	24.0	26.00	27.5	16.0	21.75	30.5	19.0	24.75
18	30.0	22.0	26.00	28.5	17.0	22.75	28.0	14.5	21.25
19	28.0	22.0	25.00	30.0	16.5	23.25	28.0	17.0	22.50
20	29.0	22.0	25.50	34.0	18.5	26.25	28.0	16.0	22.00
21	30.0	22.5	26.25	33.0	16.5	24.75	27.5	16.5	22.00
22	28.0	22.0	25.00	27.5	17.5	22.50	21.0	17.0	19.00
23	22.5	18.0	20.25	30.0	16.5	23.25	28.5	16.5	22.50
24	30.0	17.5	23.75	29.0	16.0	22.50	28.0	17.0	22.50
25	31.0	16.5	23.75	27.5	16.0	21.75	25.0	17.0	21.00
26	29.5	17.0	23.25	27.0	15.0	21.00	29.0	17.5	23.25
27	30.0	17.5	23.75	32.0	16.0	24.00	28.0	17.0	22.50
28	34.0	19.0	26.50	28.0	17.5	22.75	19.5	16.0	17.75
29	35.0	16.0	25.50	28.0	16.0	22.00	21.0	16.0	18.50
30	25.0	17.5	21.25	28.0	17.0	22.50	21.0	15.5	18.25
31	20.0	18.5	19.25	27.0	16.0	21.50	-	-	-

APPENDIX 3 (continued)

Date	OCTOBER			NOVEMBER			DECEMBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	27.5	16.0	21.75	23.5	21.0	22.25	26.0	22.0	24.00
2	26.5	10.0	18.25	27.0	19.5	23.25	27.0	22.5	24.75
3	28.0	19.0	23.50	27.0	20.0	23.50	27.0	23.0	25.00
4	28.5	21.5	25.00	25.0	20.0	22.50	26.0	22.0	24.00
5	27.5	21.5	24.00	24.0	20.0	22.00	24.5	22.5	23.50
6	27.0	22.0	24.50	23.5	21.0	22.25	23.5	22.5	23.00
7	30.0	21.0	25.50	26.5	22.0	24.25	24.5	22.0	23.25
8	26.0	22.0	24.00	26.0	22.0	24.00	27.0	22.5	24.75
9	26.0	22.0	24.00	28.0	21.5	24.75	28.0	20.0	24.00
10	26.0	22.0	24.00	27.0	22.0	24.50	24.0	21.0	22.50
11	27.5	22.0	24.75	24.0	22.0	23.00	24.5	22.5	23.50
12	30.0	22.0	26.00	24.0	22.0	23.00	22.5	23.0	22.75
13	25.0	22.0	23.50	26.0	21.0	23.50	26.5	21.5	24.00
14	26.0	22.0	24.00	24.0	21.0	22.50	25.0	21.0	23.00
15	26.0	22.0	24.00	26.0	23.0	24.50	25.0	20.0	22.50
16	24.0	22.0	23.00	26.0	16.5	21.25	24.0	20.0	22.00
17	27.0	22.0	24.50	25.0	24.0	24.50	27.0	21.0	24.00
18	26.5	21.5	24.00	24.0	24.0	24.00	24.0	20.0	22.00
19	24.0	20.0	22.00	24.0	24.0	24.00	25.5	20.5	23.00
20	26.5	22.0	24.25	27.0	22.0	24.50	24.0	21.0	22.50
21	25.5	20.0	22.75	24.0	23.0	23.50	24.5	21.0	22.75
22	26.0	22.0	24.00	26.0	24.0	25.00	24.0	23.0	23.50
23	27.0	22.0	24.50	27.0	22.0	24.50	24.5	24.0	24.25
24	25.0	21.0	23.00	25.0	23.5	24.25	25.0	23.5	24.25
25	27.5	21.0	24.25	26.0	20.0	23.00	26.0	22.0	24.00
26	27.0	21.0	24.00	25.0	20.0	22.50	26.0	22.5	24.25
27	26.0	21.0	23.50	24.5	18.0	21.25	24.5	23.0	23.75
28	26.0	21.0	23.50	25.5	14.0	19.75	25.5	23.5	24.50
29	25.0	21.0	23.00	26.0	17.5	21.75	26.0	22.5	24.25
30	26.5	19.5	23.00	25.5	20.0	22.75	27.0	23.0	25.00
31	24.5	21.0	22.75	-	-	-	27.0	22.0	24.50

APPENDIX 4 : Daily Air Temperatures in the Field in 1978. (°C)

Date	MAY			JUNE			JULY		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	7.5	5.0	6.25	23.7	11.4	17.55	15.7	13.2	14.45
2	8.9	4.3	6.60	22.8	11.7	17.25	14.7	10.1	12.40
3	15.9	8.4	12.15	23.8	13.0	18.40	13.3	8.0	10.65
4	15.6	7.3	11.45	19.3	11.2	15.25	13.0	8.0	10.50
5	9.0	3.4	6.20	18.8	11.8	15.30	12.3	8.1	10.20
6	12.0	7.2	9.60	16.0	11.0	13.50	13.7	7.0	10.35
7	12.4	8.2	10.30	14.0	11.2	12.60	16.8	10.7	13.75
8	10.3	6.7	8.50	16.4	8.8	12.60	13.1	11.6	12.35
9	16.3	6.8	11.55	16.6	7.2	11.90	16.2	12.5	14.35
10	18.3	7.3	12.80	15.2	7.2	11.20	18.9	9.5	14.20
11	17.2	6.3	11.75	20.8	9.6	15.20	17.5	12.2	14.85
12	10.7	6.9	8.80	14.2	5.6	9.90	16.8	11.2	14.00
13	11.1	6.4	8.75	11.3	7.5	9.40	21.5	14.0	17.75
14	10.8	5.5	8.15	13.0	7.8	10.40	23.3	12.2	17.75
15	12.1	5.8	8.95	12.4	5.5	8.95	20.2	9.7	14.95
16	14.5	6.2	10.35	16.3	9.4	12.85	20.4	10.4	15.40
17	15.6	4.5	10.05	17.8	7.6	12.70	21.6	11.0	16.30
18	13.2	3.6	8.40	20.0	10.6	15.30	18.2	13.1	15.65
19	14.8	6.3	10.55	23.1	10.3	16.70	16.8	11.6	14.20
20	16.0	6.8	11.40	20.0	9.8	14.90	15.3	11.6	13.45
21	14.1	9.6	11.85	15.9	9.6	12.75	18.3	11.9	15.10
22	15.6	7.7	11.65	15.3	7.9	11.60	19.2	12.8	16.00
23	17.2	8.3	12.75	15.1	6.6	10.85	15.8	11.5	13.65
24	13.7	8.1	10.90	13.1	7.5	10.30	17.3	8.9	13.10
25	16.7	7.9	12.30	15.5	10.1	12.80	18.6	12.1	15.35
26	18.8	7.0	12.90	13.7	7.5	10.60	17.7	12.0	14.85
27	20.3	9.7	15.00	14.4	10.7	12.55	20.0	14.4	17.20
28	21.5	10.2	15.85	17.6	12.0	14.80	19.8	11.6	15.70
29	21.5	10.2	15.85	16.0	9.8	12.90	22.6	14.5	18.55
30	23.3	12.9	18.10	17.0	9.1	13.05	16.6	13.7	15.15
31	25.0	12.5	18.75	-	-	-	14.3	13.2	13.75

APPENDIX 4 (continued)

Date	AUGUST			SEPTEMBER			OCTOBER		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	17.1	12.2	14.65	15.3	7.9	11.60	13.0	4.3	8.65
2	17.3	12.0	14.65	15.3	7.8	11.55	13.0	7.2	10.10
3	17.4	12.0	14.70	18.7	8.2	13.45	13.4	5.4	9.40
4	18.2	12.4	15.30	20.2	10.3	15.25	13.3	8.1	10.70
5	17.2	10.5	13.85	14.7	12.0	13.35	15.0	11.3	13.15
6	16.2	11.3	13.75	18.4	11.8	15.10	17.0	7.5	12.25
7	17.3	10.8	14.05	18.4	11.8	15.10	19.3	9.2	14.25
8	15.5	11.6	13.55	18.8	13.4	16.10	18.3	12.0	15.15
9	15.3	11.0	13.15	17.6	14.7	16.15	16.0	11.5	13.75
10	17.5	11.3	14.40	20.7	13.1	16.90	18.9	13.5	16.20
11	20.4	12.4	16.40	15.7	9.2	12.45	16.5	12.0	14.25
12	18.5	10.20	14.35	16.4	12.5	14.45	13.2	8.7	10.95
13	18.8	12.6	15.70	18.0	10.3	14.15	13.2	8.7	10.95
14	18.6	12.4	15.50	16.0	11.4	13.70	12.7	9.0	10.85
15	18.6	11.3	14.95	16.7	12.4	14.55	15.2	6.8	11.00
16	17.8	9.9	13.85	20.0	10.3	15.15	11.3	7.8	9.55
17	18.6	11.9	15.25	16.3	6.6	11.45	10.5	3.0	6.75
18	20.0	10.1	15.05	16.1	7.1	11.60	10.4	6.7	8.55
19	23.1	13.5	18.30	16.2	7.2	11.70	11.2	9.2	10.20
20	18.8	11.4	15.10	17.8	9.7	13.75	15.0	8.5	11.75
21	19.8	13.4	16.60	19.4	11.6	15.50	12.8	9.4	11.10
22	18.3	10.2	14.25	17.6	11.5	14.55	13.6	5.4	9.50
23	17.5	9.7	13.60	18.7	13.0	15.85	13.0	8.8	10.90
24	17.3	10.8	14.05	18.6	11.8	15.20	15.0	11.0	13.00
25	18.4	9.3	13.85	15.6	8.4	12.00	16.7	10.8	13.75
26	17.2	10.7	13.95	15.1	10.0	12.55	15.2	7.6	11.40
27	18.5	13.0	15.75	15.0	10.0	12.50	14.1	6.7	10.40
28	19.6	10.4	15.00	14.1	10.4	12.25	12.2	5.7	8.95
29	16.1	11.5	13.80	12.6	7.0	9.80	9.9	7.1	8.50
30	16.8	8.5	12.65	10.8	8.3	9.55	13.1	9.0	11.05
31	14.6	11.0	12.80	–	–	–	13.6	9.5	11.55

APPENDIX 4 (continued) Daily Rainfall in 1978 (mm)

Date	May	June	July	August	September	October
1	16.00	0.00	2.00	11.00	0.00	0.00
2	1.00	0.00	2.00	0.00	0.00	1.00
3	1.00	0.00	5.00	0.00	0.00	0.00
4	0.00	6.00	0.00	1.00	0.00	0.00
5	0.00	0.00	0.00	3.00	1.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	5.00	1.00	10.00	0.00	0.00
8	1.00	1.00	1.00	0.00	0.00	0.00
9	0.00	0.00	0.00	4.00	0.00	0.00
10	0.00	0.00	0.00	0.00	1.00	1.00
11	2.00	0.00	0.00	1.00	0.00	0.00
12	1.00	0.00	0.00	0.00	0.00	0.00
13	1.00	0.00	0.00	0.00	4.00	0.00
14	4.00	0.00	0.00	1.00	0.00	1.00
15	1.00	2.00	0.00	9.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	1.00	0.00	0.00
18	0.00	0.00	0.00	2.00	0.00	1.00
19	0.00	0.00	1.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	7.00	0.00	3.00	0.00	0.00
22	0.00	3.00	6.00	1.00	0.00	0.00
23	0.00	0.00	12.00	1.00	0.00	0.00
24	0.00	1.00	0.00	0.00	1.00	0.00
25	0.00	0.00	5.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	1.00	3.00	0.00	9.00	0.00
28	0.00	1.00	0.00	0.00	2.00	0.00
29	0.00	4.00	28.00	0.00	1.00	0.00
30	0.00	0.00	15.00	0.00	0.00	0.00
31	0.00	-	35.00	0.00	-	0.00
Totals	28.00	31.00	116.00	48.00	19.00	4.00